STATUS AND TRENDS REPORT

ON

DREDGING

AND

WATERWAY MODIFICATION

IN THE

SAN FRANCISCO ESTUARY

San Francisco Estuary Project

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Prepared under EPA Cooperative Agreement CE-009496-01 by the Aquatic Habitat Institute and Philip Williams & Associates Ltd.

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CONTENTS

PART TWO: WATERWAY MODIFICATION

Disclosure Statement

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This report was produced for the San Francisco Estuary Project under a Cooperative Agreement between the U.S. EPA and the Aquatic Habitat Institute.

EXECUTIVE SUMMARY

OVERVIEW

This report describes what is known about dredging and waterway modification in the San Francisco Estuary. Part One focuses on dredging; Part Two covers waterway modification.

Part One describes the need for dredging. It summarizes the roles of the various government agencies and activities of public groups in managing dredging activities. It provides information on the location of dredging projects, amounts of material dredged, and how and where dredged material is disposed. A major section of the report describes the fate of dredged material -- what ultimately happens to material disposed in the Estuary. Other key sections describe the effects of dredging on the Estuary's resources and current methods of testing dredged materials. The report provides estimates of future dredging that may occur. It also describes gaps in knowledge of the many aspects of dredging and dredged material disposal, and recommends research that would lead to better understanding and eventually better management.

Part Two of the report describes some of the main aspects of waterway modification. It focuses primarily on flooding and shoreline erosion issues. Brief sections are included on future trends, knowledge gaps and recommended research.

The management of dredging activities in the Estuary can be improved long before additional research is completed. Recognizing this, members of the San Francisco Estuary Project's Subcommittee on Dredging and Waterway Modification developed a set of goals, and lists of short-term management actions and long-term management options. These items, displayed in Appendix 4, will form the basis of future discussions and possible recommendations. Similar documents will be developed for waterway modification.

PART ONE: DREDGING AND DREDGED MATERIAL DISPOSAL.

The genesis and evolution of this report, the scope of review provided, and the necessary limitations of the report are described in the **Preface (Section I)**. The Preface explains the mechanisms and decisions that led to the preparation of the report. It also explains the steps the San Francisco Estuary Project participants will take to develop the information necessary to assist policy makers in making decisions about what must be done to properly manage dredging and dredged material disposal in the Estuary.

Section II (Introduction) provides an historical perspective on the Estuary, the extent to which human influences have modified the system, and the interactions between human engineering activities, sediment loading and sedimentation that result in the ever-present need to dredge. In summary, San Francisco Bay and the Sacramento-San Joaquin Delta (The Estuary) comprise

the largest estuary on the west coast of North America. The Estuary supports a variety of activities, including commercial and recreational fishing, recreational boating, and shipping. Historical alterations to the Estuary, mining activities in the river basins that drain into the Estuary, and diversion of water have altered the natural equilibrium between sediment input, deposition and transport to the ocean. Much of the Estuary is very shallow (more than 70% of the Estuary is less than 16 feet [5 meters] deep), and the sediments are highly dynamic, changing depth and location constantly under the influence of tides, winds and river flows.

Each year more than 4,000 oceangoing vessels, carrying cargo worth more than $25 billion move through the San Francisco Estuary. In order for the shipping industry to maintain current levels of activity, channels, waterways, turning basins and pierage require dredging to specified depths.The deepening of channels to allow safe navigation for large vessels, or for shoreline construction, creates areas of the Estuary that eventually fill with sediment. To maintain channels at a depth safe for navigation, it is necessary to dredge accumulated sediment and dispose of this material elsewhere.

Dredging and the necessary requirement to dispose of dredged material are regulated and managed at several levels of government. **Section III** of the report (**The Existing Management Structure**) describes the regulatory aspects of dredging management. It was developed with the cooperation of numerous federal, state and local governmental representatives, and with important input from representatives of several environmental and business organizations.

The *River and Harbor Act of 1868* provided for the first federally-maintained channel in the Estuary to ensure the provision of supplies and equipment to the region *via* maritime commerce. Since that time, many dredging projects have been initiated and maintained by the Federal or local governments. Private entities, including many small marina operators, also maintain channels in the Estuary.

Dredging activities in the Estuary are controlled primarily by the U. S. Army Corps of Engineers (USCOE), along with the USEPA, the California State Water Resources Control Board (SWRCB), San Francisco Bay and Central Valley Regional Water Quality Control Boards (RWQCB), and the San Francisco Bay Conservation and Development Commission (BCDC). The U.S. Coast Guard and various State and local agencies also have jurisdiction over certain activities related to dredging. The USCOE dredges those projects that are maintained by the Federal government, and grants permits to other entities for the disposal of dredged material in inland waters (under the *Federal Water Pollution Control Act*) or the ocean (under the *Marine Protection, Research, and Sanctuaries Act,* also known as the Ocean Dumping Act). The former legislation empowers the States, and thus the RWQCB, to verify that the disposal of dredged material will not violate water quality standards (through "water quality certification"). The USEPA reviews proposed projects for compliance with environmental impact criteria, and can prohibit the use of

proposed disposal sites. BCDC issues permits for dredging pursuant to the McAteer-Petris Act of 1965. Further, BCDC, as the federally-designated State Coastal Management Agency for the San Francisco Bay, requires that all projects be consistent with the Coastal Zone Management Plan adopted by the State pursuant to the *Federal Coastal Zone Management Act.* The California Coastal Commission provides consistency certifications for material disposed in the ocean.

The diversity and complexity of the existing management structure make clear that there is a requirement for more coordination among the regulatory and oversight groups concerned with dredging and dredged material disposal in the Estuary. One important conclusion of this report is that steps should be taken to improve coordination among all the agencies and organizations concerned with managing, permitting or overseeing dredging activities (**Appendix 4. Short Term Management Actions**). Coordination should be increased in order to assist in the development of a long-term, Estuary-wide management plan for dredging activities.

Historical trends in dredging and dredged material disposal activities in the Estuary are summarized in **Section IV** (**Historical Trends**). The historical data from the Estuary have not been analyzed in a comprehensive fashion previously, which is undoubtedly due to the incomplete and fragmented nature of the database. The San Francisco District of the USCOE has a reliable database for the quantity of sediment dredged in Federal Projects from 1975 to the present. The U.S. Navy also has reliable records of quantities recently dredged in their projects in the Bay. However, accurate estimates of amounts dredged in the Bay by permittees prior to 1986 do not exist. Even less information is available for the dredging projects in the Delta, which fall under the jurisdiction of the Sacramento District of the USCOE.

The San Francisco District of the USCOE and the U.S. Navy maintained many projects of varying sizes in the Bay from 1975 through 1985. Some projects required dredging infrequently, while others required dredging annually, or more often. The majority of dredged material came from four locations. In descending order of quantities dredged, these were Mare Island Strait (2.1 million cubic yards annually), Alameda Naval Air Station (600,000 cubic yards annually), Richmond Harbor (500,000 cubic yards annually), and Oakland Harbor (350,000 cubic yards annually). The actual quantities dredged at any given site varied significantly from year to year. During the period 1975-1985, an average of 4.4 million cubic yards annually were dredged from the Bay by the USCOE and the U.S. Navy.

In the Delta, there are two federal navigation projects that have been maintained by the Sacramento District of the USCOE in the past two decades, the Sacramento River Deep Water Ship Channel and the Stockton Deep Water Ship Channel. Dredging in these projects averaged 500,000 cubic yards annually from 1975-1985. Potentially significant dredging was also carried out in the Delta to maintain levees, by the 57 local Reclamation Districts, under the auspices of the Delta Levee Subventions Program administered by the

Department of Water Resources, or by the Federal Emergency Management Agency. Estimates of the amounts dredged in levee maintenance and repair are not readily available.

Coordinated effort among management and regulatory organizations should eventually result in an effective, long-term management plan for dredging activities in the Estuary.

Prior to 1972, aquatic disposal of dredged material occurred at many locations throughout the Estuary as well as in coastal waters outside the Golden Gate. Historical disposal sites were determined largely by the criteria of convenience and cost minimization. Ocean disposal included not only dredged material, but also chemical wastes, radioactive wastes, food processing wastes and obsolete munitions.

In 1972, the San Francisco District of the USCOE designated six sites in the Estuary for disposal of dredged material. This was reduced to three sites by 1975. The latter three sites are still in active use today, and are located at Alcatraz, San Pablo Bay, and Carquinez Strait. The Alcatraz disposal site received the largest volume of material from 1975-1985 (1.9 million cubic yards annually), followed by the sites at Carquinez Strait (1.5 million cubic yards annually) and San Pablo Bay (200,000 cubic yards annually). Significant quantities were also disposed of at upland sites in the Bay region (800,000 cubic yards annually) and the Delta (500,000 cubic yards annually). The reader is referred to **Section IV** and **Appendix 1** of the main report for more detailed information regarding historical dredging activities.

Section IV also provides historical data on various studies of the effects of dredged material disposal in the Estuary. These studies date from as early as 1974 and address a variety of topics, including sediment chemistry and pollutant bioavailability, tracer studies of in-Bay transport of disposed dredged material, bioaccumulation studies and the effects of suspended solids on Estuarine biota.

The current status of dredging and dredged material disposal in the Estuary is presented in **Section V** of this report (**Current Status**). More detailed information regarding dredging activities is available from the USCOE for 1986 and 1987, due in part to the requirement that permitees perform post-dredging bathymetric surveys. For this report, a detailed analysis of dredged material disposal in the Estuary was conducted for 1986 and 1987.

Section V, Part A (**Dredging and Disposal in the Estuary**) describes current dredging activities in the Estuary. As occurred historically, a few, large projects produced most of the dredged material disposed in the Estuary in 1986 and 1987. An average of 65% of material dredged was disposed of at the Alcatraz site, 11% at the Carquinez site, and 4% at the San Pablo site. The remainder was disposed in upland locations, 11% in the Bay region and 8% in the Delta. Material disposed at Alcatraz from the four largest dredging projects represented 43% of material disposed at this site by all

projects. About half of the navigation projects using the Alcatraz site disposed 100,000 cubic yards or less annually; as a group, these projects contributed less than 5% of the total quantity of sediment disposed of at the site. The amount disposed at the Alcatraz site each month was sporadic, heavily influenced by dredging activities at a few large projects during 1986 and 1987. Similar patterns occurred at the other two disposal sites.

When major dredging projects are active, disposal can be frequent. Data from the USCOE for the Alcatraz site shows that during 1986-87, ten or more disposal events occurred on 32.5% of the days, and 20 or more daily disposal events occurred 10.1% of the time. It was not common for 30 or more disposal events to occur on a single day, but 41 occurred on 31 January 1986. No disposal activity occurred 23.7% of the days during 1986-87, and data were missing for 7.1% of the days in this period.

The average rate of dredged material disposal in the Estuary as a whole during 1986 and 1987 was 7.3 million cubic yards annually. An average of 1.4 million cubic yards annually was disposed of to upland sites in the Bay and Delta regions. By comparison, these volumes are higher than in Puget Sound, where an annual average of 1.6 million cubic yards annually was dredged between 1970 and 1985. Dredging operations in the San Francisco Estuary are significantly less than those in the Rhine River Estuary at Rotterdam, Holland, where annual maintenance dredging requires the removal of 30 million cubic yards of material.

Any reasonable evaluation of the effects of dredged material disposal in the Estuary can only come about as a result of detailed dredging and disposal data. In the short term, it is imperative that the groups and agencies involved with dredged material management in the Estuary continue to keep accurate records of the exact locations of dredging activities, the volumes and types of dredged material produced and the amounts of dredged material disposed at each location. Such activities will make it possible to evaluate dredging with more than a two-year data base.

One of the more important areas for consideration in evaluation of the effects of dredging and dredged material disposal in the Estuary is the question of sediment quality and appropriate techniques for its evaluation. **Section V, Part B**, presents available data on the concentrations of contaminants in sediments of the San Francisco Estuary. Those data show that certain of the ports and harbors surrounded by urban regions are sites where the routine discharge of domestic and industrial wastes, as well as large volumes of contaminated urban runoff, led to contamination of sediments at high levels. Many of the locations with elevated contaminant concentrations in sediments (including Mare Island Strait, Richmond Harbor, and Oakland Harbor), are sites where significant amounts of dredging occur on an annual basis. The higher levels of sediment contamination at these sites probably result from three factors: (1) the preferential entrapment of fine particles in these poorly flushed locations, (2) the tendency of fine sediments to contain higher concentrations of contaminants, and (3) the existence of significant local sources of contaminants.

Sampling programs intended to characterize contaminant concentrations in prospective dredging sites should be carefully designed to establish the extent of local variation in contaminant concentrations. Regardless of the site(s) finally designated for disposal of dredged material from the Estuary, the presence of high concentrations of pollutants in domestic and industrial discharges, as well as in urban runoff and non-urban runoff will continue to cause some portion of the dredged material from the Estuary to be potentially toxic to aquatic biota. One means to reduce the magnitude of this problem is to enact aggressive pollutant source-control measures; doing so would reduce the input of pollutants to the Estuary, and would reduce the mass and magnitude of contamination in sediments.

Appropriate ways to test sediments for toxicity are a subject of some debate among scientists. Better tests for determining the ecological impact of sediments and the need for further sediment testing are necessary. The ultimate effectiveness of the testing schemes for both aquatic and upland disposal depends upon their ability to predict the potential effects sediments might cause in the environment. Laboratory tests remain imprecise predictors of such effects. One step toward improving this situation would be to design studies that provide a more accurate measurement of bioaccumulation in the field. The evaluations of dredged material impacts in this report lead to the conclusion that the agencies responsible for managing and permitting dredging activities should adopt, or endorse, a consistent, standardized procedure for testing sediment contamination and determining sediment toxicity. As part of this, agencies should expedite the development of sediment quality criteria that can be used to judge, objectively, the significance of proposed dredging and dredged material disposal activities.

There are significant gaps in our knowledge regarding the fate of dredged material disposed at the existing sites in the Estuary. **Section V, Part C** of the report addresses the question of the **Fate of Disposed Dredged Material** in detail. Although the three disposal sites used presently in the Estuary were selected for their dispersive nature, the rate of disposal of material at the Alcatraz site has exceeded its dispersive capacity, producing mounding. Virtually no accumulation of material has occurred at either the Carquinez Strait or San Pablo Bay sites, although there may be evidence for recent mounding at the Carquinez Strait site. Modeling studies and field measurements have provided some understanding of the fraction of material disposed at the Alcatraz site which remains at this location, although uncertainty still exists on this topic. A high rate of disposal of consolidated dredged material, particularly dense sediments from clamshell dredging operations, appears to be the major cause of mounding at the Alcatraz site.

The ultimate fate of dredged material transported from disposal sites is currently unknown. As the aquatic disposal of dredged sediment adds suspended material to an already turbid and dynamic environment, determining the fate of the disposed material is a challenging task that has made use of mathematical models. Efforts to develop these transport models are hampered

by the absence of data necessary to test the models and determine if they predict accurately conditions in the Estuary.

The only tracer study performed to date demonstrated that material disposed of at the Carquinez site is dispersed throughout San Pablo and Suisun Bays, and wind-driven currents appeared to be important in dispersion of the material. This study also demonstrated that material disposed of at aquatic sites in the Estuary returns to navigation channels, requiring redredging at a later period.

A substantial amount of research and monitoring is required in order to develop an adequate understanding of the fate of disposed dredged material in the Estuary. At this time, there are insufficient data to develop or verify mathematical models of sediment transport. There are inadequate data on currents and their effects on sediment resuspension in the Estuary, and sediment transport throughout the Estuary is almost completely unknown. All agencies and interested parties should be working together to secure the funding necessary to design and implement the studies necessary to eliminate these critical gaps in our knowledge of sediment behavior in the Estuary.

The principal **Environmental Effects** of dredged material disposal include the remobilization and uptake of toxic contaminants, increases in water column turbidity, and physical impacts upon the organisms that live in the sediments. These topics are addressed in **Section V, Part D.** of the report. Toxic contaminants are found in many forms in sediments, and vary in their susceptibility to mobilization. The same contaminant may occur in different forms in different sediments, indicating the importance of site-specific information. Research conducted to date suggests that significant proportions of trace metals in the sediments of the Estuary, with the exception of cadmium, are incorporated within sediment particles in a form that is generally not available to biota. Organic contaminants of concern are associated primarily with finely divided solids. Their availability to the biota is, in large part, determined by particle size and the amount of organic carbon in the sediments.

The actual behavior of contaminants in sediments upon disposal is a complex phenomenon which is not easily modeled in the laboratory. The oxidation/reduction potential of the disposal environment has an important influence upon the release of contaminants, with pH and salinity also exerting an effect upon some trace elements. Transient reductions in dissolved oxygen levels have been observed during dredging and disposal operations, particularly in the lower water column during disposal. However, the use of dispersive disposal sites in the Estuary generally ensures maximum exposure of contaminated materials to an oxidizing environment, which could increase the degree of remobilization of contaminants from sediments. The difficulty in determining actual mobilization rates for contaminants from sediments upon their disposal makes any estimate of contaminant loads from this source extremely uncertain. Given the uncertainty regarding the effects of contaminants on the biota, it is sensible to reduce the amounts of these compounds entering the Estuary.

Dredging and disposal operations inevitably increase the turbidity of receiving waters close to the sites of operation. Turbidity increases tend to be greater during disposal than during dredging, although in both cases increases in turbidity are most pronounced in the lower water column. Studies indicate that during disposal, less than 5% of the material discharged remains in the upper water column. Field studies conducted at the Alcatraz disposal site indicate that suspended sediment plumes are created during disposal operations, and these plumes move in the direction of tidal currents, dissipating completely within 20 minutes in most cases.

Laboratory studies indicate that suspended sediments can be lethal to aquatic organisms, but only at concentrations much greater than those observed in the Estuary, and much greater than those predicted to occur at dumpsites in the Estuary during periods of intense disposal activity. No research has been conducted regarding the sub-lethal effects of suspended sediments upon biota of the Estuary, nor has any investigation been made of any possible lethal effects upon sensitive life-stages.

It has been asserted by commercial and recreational fishermen, as well as some fishery agencies, that increased turbidity from disposal operations at the Alcatraz site reduces fishing success in the Central Bay. Some fishermen have suggested that turbidity due to disposal of dredged material has driven forage fish (such as smelt and anchovies) out of the Bay. This reduction in forage would cause larger species to leave the Bay to find food.

There is insufficient scientific evidence to support or refute this claim, in part because there is no long-term database regarding suspended sediments or turbidity in the Central Bay. As described above, increases in suspended sediment concentrations associated with disposal operations are transient and involve relatively low concentrations of suspended solids in the water column compared to those which are known to affect fish. Suspended sediment concentrations could reach higher levels during periods of frequent disposal (over 20 dumps per day), but this type of disposal activity has not been monitored. The concentration of suspended sediments in the Central Bay has been related to tidal stage; ebb tides draw turbid water from the shallower portions of the Estuary into the Central Bay, while flood tides lead to decreased turbidity as relatively clear ocean water is drawn into the Estuary. If the erosion and transport of sediments from the Alcatraz disposal site were controlling suspended sediment concentrations, these concentrations would demonstrate a relationship with current velocity rather than tidal stage. It is recommended that immediate steps be taken to develop a monitoring program to assess two critical aspects of the dredged material disposal question at Alcatraz: 1) the effects of dredged material disposal on turbidity in the Central Bay, and 2) the determination of residual pollutant loads (particulate and dissolved) in the water column after the disappearance of residual turbidity.

Dredging and the aquatic disposal of dredged material have some unavoidable impacts upon bottom-dwelling communities (the benthos), particularly when the grain size of disposed material is different than that

existing at a disposal site. Benthic assemblages at existing dredging and disposal sites, and elsewhere in the Estuary, tend to be dominated by organisms that are well-adapted to changes in bottom sediments. The fact that benthic species in the Estuary are adapted to the dynamic environment that characterizes much of the Estuary, and are reproductively active for much of the year, suggests that such communities are very resilient and may not be harmed by the physical impacts of dredging and disposal. Nevertheless, transient impacts on benthic communities undoubtedly occur through dredging and disposal operations. Significant effects upon the benthos are also likely to occur at new disposal sites. This may be particularly true at near-shore ocean sites that are characterized by more stable benthic assemblages and sediments of different grain size. Potential impacts at very deep ocean sites have yet to be assessed.

Section V, **Part E** describes **Present Testing Requirements** for dredging projects. It notes the controversy that exists over the interpretation of sediment bioassay data obtained from different experimental contexts, i.e., the apparent effects threshold, the sediment Triad, and the prediction of effects based upon the chemical factors that determine the physical fate of the contaminants. While all these approaches have their advantages, none can be said to be entirely predictive of effects at every site and in every situation. Care must be taken in the interpretation of bioassay data, and the potential for dredged material to cause impacts must be assessed based upon objective scientific judgment as well as from numerical criteria designed to protect human health and biological resources.

Future Trends in dredging and dredged material disposal are difficult to estimate; these estimates are the subject of **Section VI** of the report. Any initiation of new dredging projects will be influenced by the availability of funding, public opinion, agency approval, shifts in policies (such as decisions to close military bases), and trends in commercial shipping. The amount of maintenance dredging will be influenced by environmental variables such as sedimentation rates, runoff, and the timing of water diversions. Recent data indicate that new work projects heavily influence the amounts dredged and disposed in a given year, and thus future new work can be expected to significantly affect the accuracy of trend estimates.

The USCOE and the U.S. Navy have prepared estimates of maintenance and new work dredging to be undertaken in the near future. These estimates suggest that approximately 6 million cubic yards of maintenance dredging will occur annually between 1989 and 1992. Several major new work projects are expected to begin by 1992, including 15.4 million cubic yards by the San Francisco District, 8.5 million cubic yards by the Sacramento District, and 1.7 million cubic yards by the U.S. Navy.

Section VI also presents a summary of the most important **Gaps in Knowledge** about dredging, dredged material disposal, and the extent to which these activities affect the physical and biological status of the Estuary. Questions about the physical nature of sediment budgets, sediment transport,

sediment resuspension and the association of contaminants with sediments characterize the most important gaps in our existing knowledge. Without an adequate understanding of these processes it will be extremely difficult to predict sediment behavior in the Estuary, to ascertain the extent to which sediment transport serves as a vector for the transport of contaminants throughout the system, and to make reasonable predictions about the potential impacts of sediments on the biota. The studies necessary to come to the point of understanding these processes may take a long time, and may be very expensive.

This report has been reviewed by persons representing many agencies, authorities, organizations and institutions. The many comments that have been provided through two rounds of review have served to make this document responsive to the needs of all interested parties. Comments on the second draft are presented in **Appendix 3**.

RECOMMENDED RESEARCH AND MONITORING

It is clear that there are significant gaps in our present knowledge of dredging in the San Francisco Estuary. The areas of uncertainty vary in their ease and cost of study, and their importance to the management of dredging and waterway modification in the Estuary. Major gaps in knowledge exist for two major environmental concerns: (1) the effects of the disposal of contaminated sediments, and (2) whether dredged material disposal affects fishing success by increasing suspended sediment concentrations around disposal sites.

It is possible to conduct additional research to address the latter question, but the impact of dredged material disposal upon contaminant concentrations in the water column and organisms of the Estuary will not be an easy question to answer. Carefully designed, well-managed research and monitoring studies will clarify the environmental impact of dredged material disposal in the Estuary. Because of the many sources of contamination in the Estuary, it is possible that cessation of disposal in the Bay would have no detectable impact on contaminant burdens in the biota of the Estuary. Conversely, if the many sources of contamination in the Estuary were controlled, and sediment contaminant burdens tended toward a new, lower equilibrium, it is possible that disposal of dredged material in the Bay could be maintained, and contaminant burdens in biota could decline. Finally, whether such a decline would be detectable, or significant, with regard to potential sublethal effects of contaminants on organisms, is unclear. This is due to the wide range of variability seen in environmental samples from any location.

Although it is possible to make management decisions regarding contamination in dredged sediments without additional scientific study, there are key scientific and technical issues that could be examined to give decision-makers the best information for policy and management decisions. These research needs are described in detail in the report. The inclusion of this list of recommended research should in no way be interpreted that these studies must

be completed prior to improving management decisions about the disposal of dredged material and waterway modification in the San Francisco Estuary.

Some of our gaps in knowledge can be filled only by studies that can be completed in a time-frame that benefits ocean site designation and would not meet some of the data needs for existing dredged material disposal operations. It is recommended that

The following subject areas need to be better understood in order to effectively manage dredging and dredged material disposal in the Estuary.

1. ***The precise amounts and frequency of dredged material disposed at sites in the Estuary***. It is recommended that more detailed data be collected and routinely analyzed to provide precise information regarding dredging and disposal activities in the Estuary. This is particularly the case with respect to dredging activities carried out by organizations under permit from the USCOE.

2. ***The ecological significance of test results, including bulk chemistry assays, toxicity bioassays, and bioaccumulation tests.*** The precise relationship between laboratory tests using contaminated sediment and the actual effects resulting from disposal of this sediment in the Estuary will probably never be determined. This is due to difficulties in conducting controlled field experiments, given the extraordinary number of factors that influence contaminant release, bioavailability, and toxic effects under field conditions. Laboratory studies can, however, provide useful information, particularly for testing "worst case" conditions. It is recommended that regulatory agencies work to develop a more objective method by which the results of sediment testing can be evaluated. Studies should also be undertaken to investigate the causal mechanism of the toxic responses observed in sediment bioassays.

3. ***The ultimate fate of disposed material in the Estuary***. Knowledge of the fate of disposed material in the context of natural cycling of sediments in the Estuary is vital for two important management issues: 1) the amounts of dredged material returning to navigation channels, and 2) the distribution of the contaminants associated with dredged material. This topic can be investigated using both models and tracer studies. Recommended research should include, but not be limited to the following studies.

(i) It is recommended that the modeling effort currently underway by the USCOE be continued, with a clear focus upon circumventing existing limitations in the models.

(ii) It is also recommended that tracer studies be conducted to define the short and long-term transport of suspended particles from estuarine disposal sites. These studies could provide information regarding the return of disposed material to navigation channels, the dispersion of disposed material under different hydrological regimes, and the

possible contribution of dredged material disposal to "hot spot" formation in the Estuary.

4. ***The bioavailability of contaminants released by disposal of dredged material.*** Data regarding the bioavailability of contaminants released from dredged material is essential to determine the potential for toxicological effects due to the bioaccumulation of contaminants. It is recommended that a routine biomonitoring program be established at the major aquatic disposal sites in the Estuary. This program should utilize the California mussel (*Mytilus californianus*), and follow the established procedures for the use of biomonitors.

5. ***The distribution of suspended solids concentrations near disposal sites.*** It is recommended that the concentration of suspended solids be monitored throughout the water column at the disposal sites in the Estuary, with an emphasis on understanding the contribution of dredged material disposal to suspended sediment levels. In particular, the suspended sediment concentrations in the Central Bay during periods of frequent use of the Alcatraz disposal site should be documented.

6. ***The impact of suspended solids from dredging operations on sensitive estuarine biota***. It is recommended that studies be carried out to determine the extent to which suspended sediments affect estuarine biota. Such studies should include reviews of available data as well as laboratory research to examine the possible acute and chronic impact of suspended sediments upon sensitive estuarine biota, including life-history stages that could be exposed to sediment plumes from dredging and disposal operations. Commercially-important species should be emphasized in such studies, and experiments should be designed to simulate field conditions to the maximum possible extent.

PART TWO: WATERWAY MODIFICATION

Waterway modification in the Estuary has been substantial. The **Introduction** (**Section I**) of Part Two of the report lists some of the major factors related to waterway modification in the Estuary. **Section II** of Part Two (**Existing Management Structure**) describes the federal and state agencies that have responsibility for flood protection planning and shoreline protection.

Section III of Part Two (**Historical Trends**) describes past activities that have led to the fact that many of the low-lying areas around the San Francisco Bay Estuary have a substantial risk of flooding. These trends include a natural rise in ambient sea-level and modifications in various waterways that impact peak flood flows as well as the total volume of freshwater that is discharged from the drainage basin into the Estuary. Human influences have altered waterways by virtue of levees constructed in the Delta, by substantial alterations to patterns of sedimentation at several times, such as during the gold-rush period, and by channelization of streams in urban areas.

The **Current Status** of waterway modification in the Estuary is described in **Section IV** of Part Two of the report. As for flood potential, the Delta region is the most susceptible to an increased frequency of flooding. Permanent inundation of major parts of the Delta would undoubtedly have a significant effect on the physical characteristics and hydrodynamics of the Estuary. The costs of permanent flooding also include the value of the inundated farmland, gas extraction, the effect of increased salinity on water exports, and any adverse effects upon fisheries in the Estuary. The major causes of this problem are inadequately constructed or poorly designed levees, inadequate internal drainage systems, improper land uses in flood-prone areas, or inadequate maintenance of flood control facilities. The situation in the Delta is complicated by the fact that there is no single agency concerned with long-term planning, including integrated land use, environmental resource protection, and water resources management. Even without considering potential future climatic changes, it is likely that the risk of flooding in the environs of the Estuary will increase due to land subsidence, existing rates of sea-level rise, and deterioration of levees. The changes in climate that have been predicted to occur due to global warming could substantially increase the risk of flooding, due to an accelerated rate of sea-level rise, and an increase in the frequency of winter floods in the Central Valley. Design standards to protect against flooding are inconsistent, and not based on the most recent hydrologic data.

Shoreline erosion is threatening the long-term existence of significant areas of remnant tidal wetlands around the Bay, as well as the integrity of some levees. The causes of shoreline erosion have not been comprehensively investigated, but may be related to the reduction of sediment inflow to the Bay over the last 50 years.

Future Trends related to waterway modification are discussed in **Section V** of Part Two of the report. The main concerns for the future include flooding of waterfront lands due to a combination of levee failure in the Delta and the progress of sea level rise in the Delta and in coastal regions. Sea level rise could be exacerbated by global warming (the "greenhouse effect.") Problems of shoreline erosion are related to changes in the overall sediment budget of the Estuary, as well as to the problems of levee failure and sea-level rise combining to allow increased wave action against shorelines.

RECOMMENDED RESEARCH AND MONITORING

Much is unknown about the effects of waterway modification in the Estuary. Review of the data suggest that the potential for shoreline erosion, levee failure and flooding in the lands around the Estuary can be reduced by certain management practices; however, additional data are needed to understand fully the actions that need to be undertaken in order to protect fully against predicted increases in sea-level rise and its effects.

It is recommended that the following research be undertaken in order to maintain shoreline areas, and to protect adequately against the consequences of already having modified existing waterways to their current state:.

1. ***The impact of coastal flooding***. Estimates of 100-year high water levels around the Estuary should be updated and revised to systematically account for the joint probability of flood flows and storm surges. Consistent flood protection design standards should be developed for different land uses around the Estuary, and future planning for coastal flood protection should take into account projected future sea-level rise. The consequences of failure of the Delta islands upon San Francisco Bay morphology, hydrodynamics, and salinity distribution need to be analyzed to determine management strategies for the Delta. In addition, it is recommended that a comprehensive survey of the condition and elevation of all perimeter levees surrounding the Bay be undertaken; there is a also a need for a detailed topographic survey of low-lying areas around the Bay, to determine areas of risk under future hazard scenarios.

2. ***The problem of shoreline erosion***. Existing bathymetric surveys and sediment transport data should be analyzed to update the sediment budget for the Estuary. Periodic bathymetric surveys need to be made of mudflat and shallow inter-tidal areas to monitor long-term changes in Bay morphology that might affect shoreline erosion. There is also a need for a coordinated, long-term plan for the future of the Delta.

PART ONE

DREDGING AND DREDGED MATERIAL DISPOSAL

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I. PREFACE

In recognition of the special need to protect the water quality and natural resources of our nation's estuaries, Congress passed the *Water Quality Act of 1987*. This act amended the *Clean Water Act* and established the National Estuary Program. The Program, administered by the U.S. Environmental Protection Agency, requires the development of Comprehensive Conservation and Management Plans (CCMP) for the nation's most significant estuaries.

As enabled by the *Water Quality Act*, the Governor of California nominated the San Francisco Bay/Sacramento-San Joaquin Delta for inclusion into the National Estuary Program. In response, the Administrator of EPA formally established the San Francisco Estuary Project (the Project) in April, 1988. It is a planning effort with broad-based involvement of the public and local, state, and federal agencies. The Project's goals adopted by its participants are:

1. Develop a comprehensive understanding of environmental and public health values attributable to the Bay and Delta and how these values interact with social and economic factors.
2. Achieve effective, united, and ongoing management of the Bay and Delta.
3. Develop a Comprehensive Conservation and Management Plan to restore and maintain the chemical, physical, and biological integrity of the Bay and Delta, including restoration and maintenance of water quality, a balanced indigenous population of shellfish, fish, and wildlife, and recreation activities in the Bay and Delta, and assure that the beneficial uses of the Bay and Delta are protected.
4. Recommend priority corrective actions and compliance schedules addressing point and non-point sources of pollution. These recommendations will include short and long-term components based on the best scientific information available.

Under authority of the *Water Quality Act*, the Project has five years in which to convene a Management Conference, identify and characterize the Estuary's priority problems, and develop a CCMP. The Project is scheduled to complete the CCMP by November 1992. After adoption by the Management Conference, the CCMP must be approved by the Governor of California and the Administrator of EPA. Once approved, the Plan will guide local, state, and federal agencies in efforts to improve protection of the Estuary.

The Project's Management Conference, with over one hundred participants from environmental, business, and government interests has identified five management issues of concern: 1) Decline of Biological Resources, 2) Increased Pollutants, 3) Freshwater Diversion and Altered Flow Regime, 4) Increased Waterway Modification, and 5) Intensified Land Use.

To characterize and better define the management issues, the Project is preparing a series of Status and Trends Reports. These technical reports seek to develop a scientific consensus on the major aspects of the issues and identify important gaps in information and knowledge. In this characterization phase of the

Project, individual Project subcommittees oversee the development of these reports. Status and Trends Reports are being prepared on: 1) Dredging and Waterway Modification, 2) Wetlands and Other Habitats, 3) Land Use and Population, 4) Pollutants, 5) Aquatic Resources, and 6) Wildlife.

Several other technical reports are also being prepared during the characterization phase of the Project. A report on land use impacts and regulation is being prepared on the relationship between land use and estuarine conditions. A report on quality assurance and quality control of pollutants analysis will assess the changes needed to improve technical procedures of pollutant analysis. A report evaluating the regulatory, institutional, and management programs will develop an understanding of the relevant regulatory responsibilities and lay the groundwork for improving protection of the Estuary. In addition, an analysis of freshwater flow and altered flow regimes will be undertaken.

The characterization effort will culminate in the completion of a "State of the Estuary" report. This report will summarize the information in the individual technical reports and provide an objective assessment of current conditions in the Estuary. This assessment will form the basis for the Project to develop actions for inclusion in the CCMP.

This Status and Trends Report deals with one of the five Project Management issues -- Waterway Modification. Although Project participants initially considered dredging to be a subset of the Waterway Modification management issue, given its perceived importance by so many project members, dredging became the major area of focus. Accordingly, the issue came to be known as Dredging and Waterway Modification. This report is, accordingly, divided into two parts, the first on Dredging and the second on Waterway Modification.

Participants representing all areas of the Estuary are active on Project committees and subcommittees. Given the concerns of the participants who volunteered to serve on the Dredging and Waterway Modification Subcommittee, this report focuses more on the Bay than on the Delta. This does not mean that the Delta is without its own unique and important set of dredging and waterway modification issues. Rather, it reflects the interests of those who were most active as the report was being developed and reviewed.

This report is the product of more than a year's effort by members of the Dredging and Waterway Modification Subcommittee, the consultants, and Project staff. It is based on the review of two drafts by more than seventy individuals with a wide range of viewpoints and expertise. More than twenty sets of comments were submitted on the first draft. All comments on the second draft are displayed as Appendix 3.

After reviewing the first and second drafts of this report, the Dredging and Waterway Modification Subcommittee developed a set of goals for dredging and completed lists of short-term management actions and long-term management options. These documents were discussed and adopted by the Management Committee on March 16, 1990. The goals, actions and options are displayed in Appendix 4.

The Subcommittee has not yet developed goals, actions and options for waterway modification. It will complete these tasks before presenting the report to the public.

To solicit additional input on the dredging and waterway modification management issue, the Project will present the report at several public workshops. Comments on the short-term actions and the long-term options will be sought. Subsequently, Project participants will re-assess the short-term actions and begin to implement them. Project participants will discuss the public input on the long-term options, and begin to select the most promising for evaluation and eventual inclusion into the CCMP. Using this approach, the Project will be able to develop a CCMP that is responsive to the public, elected officials, and government agencies.

II. INTRODUCTION

San Francisco Bay and the Sacramento-San Joaquin Delta (the Estuary) form the largest estuary on the western coast of North America, with a surface area of 1,240 km^2 and a drainage basin of 153,000 km^2 (Fig. 1; Conomos *et al.*, 1985). By virtue of its topography, productive waters, and shelter, the Estuary has developed as a center for fishing, shipping, and recreational boating.

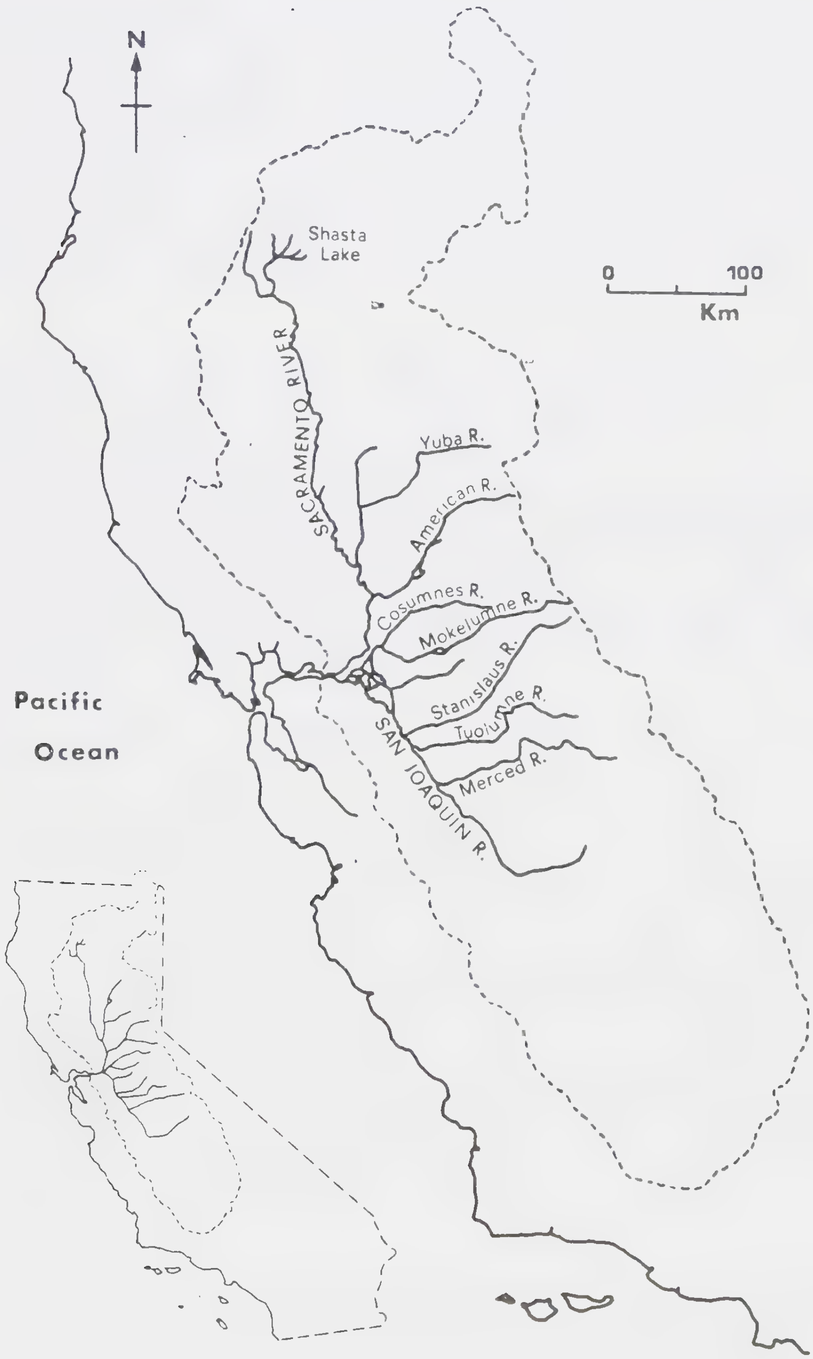
Such diverse uses often lead to significant anthropogenic changes in estuarine systems. Most changes have been imposed due to efforts to maintain or optimize the function of the Estuary for a specific purpose. Thus, the need to maintain shipping channels at desired depths may lead to alterations in flow and sedimentation as the result of dredging (Conomos *et al.*, 1985); the desire to maximize fish production may lead to overfishing and the destruction of fisheries resources (McHugh, 1976); and accommodation of a growing population may lead to deterioration of water quality as greater volumes of wastewater are discharged into estuaries as receiving waters (Gross, 1976; O'Connor *et al.*, 1977). The San Francisco Estuary and its drainage basin exhibit the same types of anthropogenic effects as other estuaries in the United States (Gross, 1976; Schemel *et al.*, 1984).

It is the goal of this report to describe our present knowledge of dredging and dredged material disposal in the San Francisco Estuary, to identify trends in dredging-related activities, and to derive from the information available an interpretation of the future of dredged material disposal in the Estuary. Both "status" and "trends" in this report will be interpreted broadly to include not only information on dredging activities, but also the spectrum of effects that disposed dredged material might have on the San Francisco Estuary ecosystem (i.e., possible increases in turbidity, transport and redistribution of contaminants, impacts on fisheries, and other effects).

The subject of dredged material disposal in aquatic systems is not a simple exercise in civil engineering. It involves detailed considerations of the physics and chemistry of sediments; the physics, chemistry, and toxicology of contaminants that may be associated with sediments; and the interaction of sediments, dredged material, contaminants, and estuarine hydrology with existing populations of shellfish, fish, and wildlife. The complexity of this subject, and the sparse information available for drawing specific conclusions, makes it necessary that existing Estuarine resources be protected by making reasonable decisions based upon available data, while new knowledge - that intended to fill the existing gaps in understanding - is accumulated. Whether such decisions involve action or further study is a policy question outside the scope of this report. This report provides a description of available data, as well as a detailed list of those areas in which additional data are sorely needed for future decisions on dredging, dredged material disposal, and the maintenance of the aquatic habitat of the San Francisco Bay Estuary. That this report contains recommendations for research is not an endorsement of policies that may call for deferment of regulatory action until studies are completed.

The following section will describe briefly the impacts of human settlement on the Estuary, particularly alteration of the habitat and historical sedimentation patterns.

Fig. 1. Map of the San Francisco Estuary and its basin. Inset shows the relationship of the Estuary and its basin to the State of California. After Wright and Phillips (1988).



Dredging in the Estuary will be summarized, as will the processes of sedimentation and sediment resuspension, the need for dredging in the Estuary, and the disposal of dredged material.

A. HUMAN INFLUENCES

The Estuary has witnessed numerous changes since its initial colonization in 1769. In particular, the physical character of the San Francisco Estuary has been altered since rapid colonization of the Bay margins and the basin began about two hundred years ago (Nichols *et al.*, 1986). Several major factors contributing to physical changes in the Estuary were 1) hydraulic gold mining in the late 1800s, 2) the reclamation of land in the Delta and the Bay margins (from about 1850 to the present), and 3) agricultural development of the Central Valley. Each of these events has altered the natural sedimentation regime in the Bay and Delta through changes in the natural sediment loading and/or through effects on the hydrodynamics of the Estuary.

Hydraulic gold mining technology was used in the Sierra Nevada from 1853 to 1884. Application of this new technology brought large quantities of sediments into the Delta and the Bay from the upper drainage basin, causing blockage of many waterways and flooding during heavy rainfall. The amount of sedimentation in the system was so large that, even after hydraulic mining was stopped by court injunction (1884), it was decades before the Sacramento River was flushed out and returned to its natural depth. Smaller rivers took even longer to recover (Gilbert, 1917; Krone, 1979). Gilbert (1917) calculated that about 1 billion cubic yards (yd^3) (0.76 billion m^3) of sediment were deposited in the northern reach of the Estuary (Suisun Bay/San Pablo Bay) between 1849 and 1914. Early in the 20th century, this process had deposited a new layer of sediment from 0.25 to 1.0 m thick in the northern reach of the Estuary (Gilbert, 1917), altering the volume and tidal prism of the Bay and affecting circulation patterns (Nichols *et al.*, 1986).

Marshlands are essential elements in the balance of sediment transport and deposition in estuarine systems and most of the marshlands in the Estuary have been eliminated. Prior to 1850 there existed 2,200 km^2 of marshland in the Delta and around the Bay margins (Atwater *et al.*, 1979; Josselyn and Atwater, 1982). The area of these tidal marshes was greater than the surface area of the Bay. Some 64% of the marshland was in the Delta. The Delta marshlands were the first to be leveed, and many were reclaimed as farmland prior to 1920. The majority of the marshes on the Bay margins survived until later in the 1900s, when many were developed into salt evaporation ponds or were reclaimed for residential or commercial use. Only 125 km^2 of tidal marshland exist in the Estuary today. This is about 6% of the original area; interestingly, about one third of the present tidal wetland area has formed since 1850 (Atwater *et al.*, 1979).

Like the direct introduction of large quantities of sediments from hydraulic gold mining, water projects in the Central Valley had a direct effect on the sediment balance of the Estuary. Shasta Dam on the Sacramento River (completed in 1944) and many other dams and canals have resulted in substantial alterations to the freshwater flow regime in the Estuary, and have reduced sediment loads in those flows (Krone, 1974).

B. SEDIMENTATION PATTERNS IN THE ESTUARY

1. Sediments and Sedimentation

For this report, the most important consideration is the distribution and transport of sedimentary material in the San Francisco Estuary. Suspended and deposited sediment is classified by particle size, as follows: 1) sand (particle diameter greater than 20 micrometers [μm]); 2) silt (particle diameter 2 to 20 μm); and clay (particle diameter less than 2 μm; Ehrlich *et al.*, 1977). The "diameter" referred to is a functional parameter, the "effective settling diameter" or "Stokes diameter" of a particle, derived from the rate of settling of a particle under controlled conditions. Stokes diameter is predicted by Stokes Law, which states that settling velocities for particles are proportional to the radius of the particle, squared. Therefore, clay particles of very small diameters remain in suspension for longer periods of time than larger silt and sand particles.

Three factors interact to determine deposition of particles in an estuarine system. These are 1) the velocity of the water, 2) the turbulence in the water column, and 3) the size of the particles in question (Schubel and Carter, 1984). In zones of high velocity and turbulence, only the largest particles (sand) will deposit. In zones of low velocity and turbulence, sand, as well as the smaller particles (silts and clays) will settle to the bottom. Gradients in water flow and turbulence in aquatic habitats will result in "sorting" of particles in the sedimentary deposits, such that one might find deposits of nearly pure sand in one location (high flow, high turbulence), while other locations may have sediments with nearly pure deposits of silt and clay (low velocity, low turbulence; Ehrlich *et al.*, 1977).

Sediment deposits are not static. Once particles have deposited, they are subject to resuspension and transport away from the site of deposition. As with deposition, resuspension of deposited sediments depends upon water velocity, turbulence, and the size of the particle (Mehta *et al.*, 1982). Sediment resuspension is more complex than deposition, however, in that factors such as packing and cohesion of the sediment deposit affect the minimum velocity or turbulence required for resuspension. Fine sands that are tightly packed, for example, may be very resistant to erosion and resuspension. Clay particles and silt particles with a high organic carbon content are also resistant to erosion because the organic matter tends to make the fine particles adhere to one another, forming a barrier that resists the shearing effects of flowing water. In fact, deposits of cohesive, finely divided sediments (silts and clays) may be much more resistant to erosion and resuspension than deposits of coarse, unconsolidated sands (Mehta *et al.*, 1982).

Like all estuaries, the San Francisco Estuary is a filter and a trap for suspended particulate matter (Schubel and Kennedy, 1984). Partially mixed estuaries, like the San Francisco Estuary, are the most efficient filters for fine-grained suspended matter (Schubel and Carter, 1977) because water movement, turbulence, and velocity are variable, changing with shifts in tide, wind, freshwater inflow, and a number of other factors. As a result, water velocity frequently reaches zero at all points, allowing fine-grained materials to accumulate in shoal areas and backwaters, as well as in

channels and sloughs throughout the Estuary. Only those portions of the Estuary with high-velocity currents are devoid of finely divided, deposited sediments.

The depth of water over deposits of "fines" (silts and clays) will vary depending upon the currents and turbulence at the site. Open areas of the Estuary exposed to the wind will be highly turbulent environments. Finely divided materials in sedimentary deposits at such sites will resuspend easily. In more sheltered areas, where wind-induced turbulence may be less, fine materials will be less subject to erosion and such sites will tend to shoal more.

The mechanics of sediment deposition, resuspension, and transport are the same in all estuaries. However, each estuary also differs, having unique sources of mineral and organic material within its drainage basin. The remainder of this chapter discusses the unique situation of the San Francisco Estuary and its sediments as influenced by human activity over the past 200 years.

2. Sediment Loading

Most estuaries exhibit a dynamic equilibrium between sedimentation and erosion; natural sediment loading during periods of erosion in the drainage basin is balanced by losses of suspended particles to offshore waters and deposition within the estuary. However, changes in the rates or patterns of sediment loading to an estuary, as well as any changes in hydrodynamics affecting sediment transport will cause a shift in the equilibrium. In the case of the San Francisco Estuary, the sediment cycle was affected by heavy burdens of sediment from the time that hydraulic technology was used in gold mining (1870's-1880's), the reduction of peak freshwater by the water projects, and the elimination of marshland sedimentation traps (Atwater *et al.*, 1979). These factors have altered sedimentation patterns in the Estuary.

Krone (1966, 1979) showed that areas of the Bay have exhibited either net sediment accumulation or net erosion over very long time periods. Deposition of fine sediments occurred in Suisun Bay, Grizzly Bay, and San Pablo Bay during and immediately following hydraulic gold mining. These sediments were later eroded and transported further downstream to Central Bay. More recent changes, such as the diversion of water from the head of the Estuary, interact with this long-term cycle to produce complex patterns of sedimentation and erosion in the Bay and its sub-embayments. This process is no doubt continuing at present, but is not completely understood. Dams and water diversions have decreased the sediment loading to the Estuary significantly. It has been predicted that any future increase in water diversions will cause a further decrease in sedimentation (Krone, 1979).

Overlaid upon such long-term changes are medium- or short-term events that may disturb the deposition/erosion regime of sediments in the Estuary. An example of medium-term events might be those due to individual reclamation projects that may alter flow patterns in localized areas of the Estuary. Such alterations of flow patterns will have the effect of disturbing a pre-existing equilibrium that controls sediment deposition, resuspension, depth of deposition, and overall stability of the sedimentary deposit. Both freshwater inflows and wind strengths vary seasonally, and these factors are important in defining inflows of suspended solids and the erosion of sediments.

Short-term events include those created by storms or tides. In certain areas of the Bay and Delta, it is likely that no true equilibrium between sedimentation of material and resuspension through erosion has yet been attained. In other regions, equilibrium conditions that have been attained may be disturbed by future activities. The substrate of the Bay and Delta must thus be considered to be dynamic in nature, responding to many factors by complex alterations in the local sedimentation/erosion regimes.

Krone (1966, 1979) showed that the Sacramento and San Joaquin rivers are the most important source of new sediment to the Estuary. Together, these two rivers account for 76% of the annual sediment load entering the Bay (annual averages as of 1960; Krone, 1966, 1979). The remainder of the new sediment load is from streams entering Suisun Bay (5% of total), San Pablo Bay (7%) and Central and South bays (12%). The total amount of new sediment deposited in the Bay annually was calculated to be 4.38 million tonnes (wet wt.; metric tonnes = 1,000 kg)(Krone, 1966, 1979). The USCOE (1965) made a similar estimate of sediment loading based upon the demand for dredging in the Estuary.

3. Resuspension, Transport and Redeposition of Sediments

Not only does new sediment enter the Bay and Delta every year from upstream sources, but sediments in the Estuary are also constantly resuspended, transported, and redeposited in new locations. Relatively little is known about sediment resuspension, transport, and redeposition in the Estuary. However, since the Bay is very shallow (40% is less than 2 m deep, and 70% less is than 5 m deep; see Sustar, 1982; Nichols and Thompson, 1985a), most authors consider that local rates of resuspension and redeposition of sediments are high compared to other major estuarine systems (e.g., the Chesapeake Bay, Hudson River, and Puget Sound).

The sediments of the Bay are highly mobile. In shoal areas sediment resuspension is probably due to wind-driven turbulence. However, even sediments within the deeper channels of the Bay are highly mobile (e.g., see SAIC, 1987a), presumably due to the large tidal prism of the Bay and strong currents close to the sediment-water interface.

C. DREDGING REQUIREMENTS AND PRACTICES

1. The Need for Dredging

Estuarine systems tend to equilibrium with regard to sediment import, deposition, resuspension, transport, and export. However, in urban-industrialized estuaries like San Francisco Bay, human alterations to bottom topography may change these processes quite radically. While one might expect an equilibrium among sediments in the various compartments of a natural system, estuaries that have been dredged, filled, and otherwise "improved" usually show sediment accretion in artificially maintained channels and deeper marginal areas. As shown by Sustar (1982), any dredged channel or basin artificially maintained at depths greater than the surrounding sediments will tend to fill, as the artificially deep area will be out of equilibrium with the surrounding bottom. This is particularly noticeable in the San Francisco Estuary, especially in areas where the prevailing currents intersect or cross

channels rather than following them and in quiescent areas where particles can settle out.

The most important reason for dredging in the San Francisco Bay-Delta Estuary is to maintain or improve the depth of shipping channels, approach channels, turning basins, and docking slips. However, other reasons also exist for the dredging of particular portions of the San Francisco Bay and Delta. For example, flood channels must be maintained at adequate depths to provide for efficient removal of runoff during storm events without threatening any surrounding low-lying areas, and the construction of various structures such as bridges or breakwaters require dredging of underlying marine deposits to provide secure and safe footing.

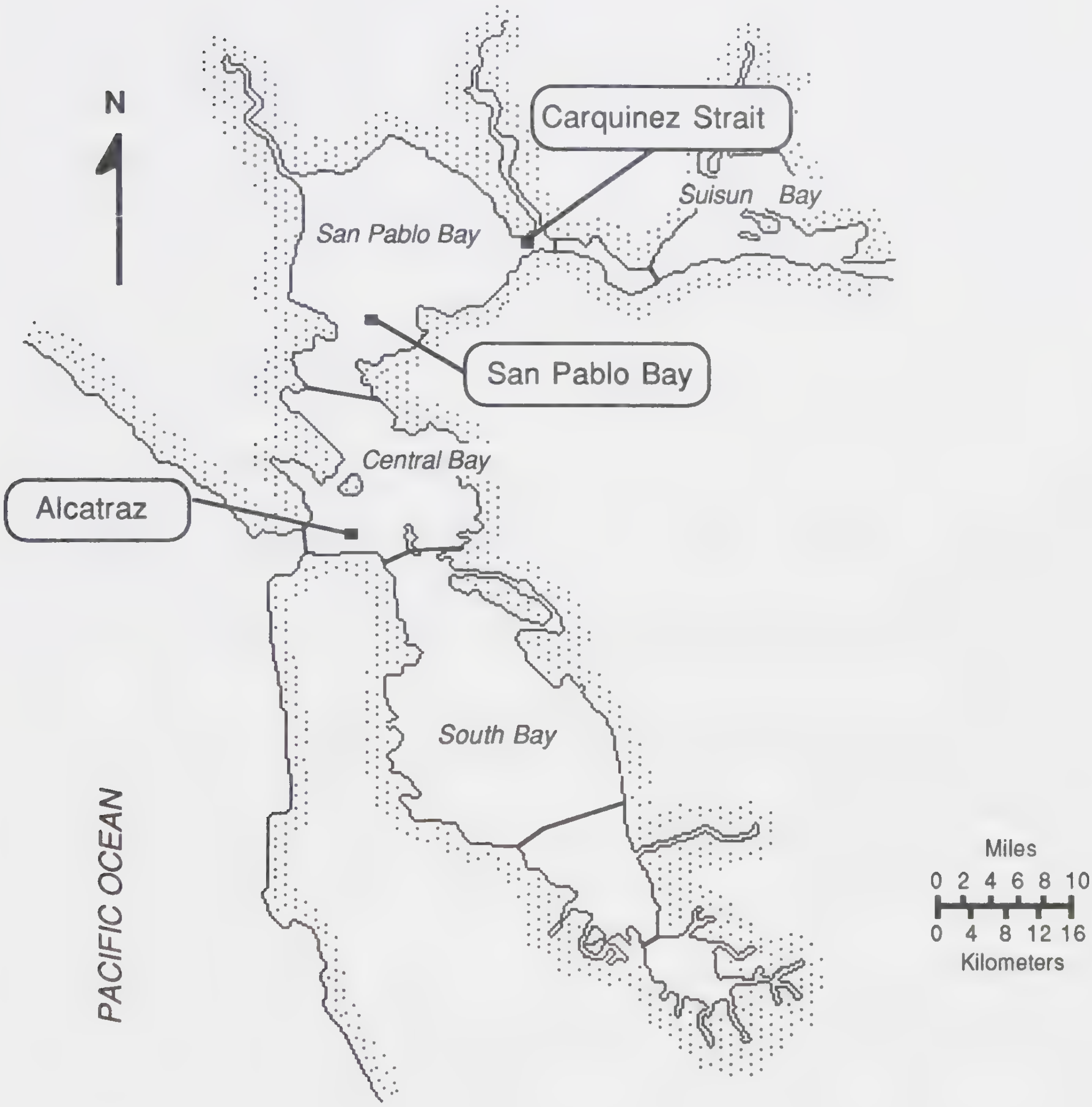
Each year approximately 4,000 commercial oceangoing vessels move through the Estuary, carrying over 50 million tonnes of cargo valued at an estimated $25 billion (Golden Gate Ports Association, 1988). For the shipping industry to maintain current levels of activity, vessels must have access to the several ports along the Bay margin. As a result, the principal channels of the Bay and Delta must be dredged if navigability is to be maintained. In addition, many proposed projects, if carried out, would require new dredging. Such new projects include 1) construction of marinas or small boat harbors, 2) alterations to the Bay margins for the reclamation of land, and 3) deepening of access routes to major port facilities such as the Oakland Container Terminal.

The majority of the dredging in the Estuary is carried out by the U.S. Army Corps of Engineers (USCOE). The USCOE maintains navigation channels in the Estuary, and performs federally sponsored navigation and port improvement projects. In addition, the U.S. Navy and the Ports of Oakland and San Francisco undertake significant amounts of dredging under permits from the USCOE. Other organizations, such as the flood control districts and marina operators, also perform dredging in the Estuary. However, only relatively small amounts of sediment are dredged by such organizations (San Francisco Bay Conservation and Development Commission [BCDC], 1988; San Francisco Bay Regional Water Quality Control Board [SFBRWQCB], 1988).

2. Disposal of Dredged Material

Until the late 1970s, the principal criterion for the selection of a dredged material disposal site in the Estuary was its proximity to one or more ongoing or planned dredging projects in the Bay or Delta. As a result, there were many disposal sites in the Estuary (see discussion in Section IV). In the early 1970s environmental considerations began to exert a strong influence on dredged material disposal practices. As a result, the USCOE restricted the in-water disposal of dredged material to three sites in the Estuary. These are 1) at the western end of the Carquinez Strait; 2) in the central part of San Pablo Bay; and 3) to the south of Alcatraz Island (Fig. 2). The rationale behind the selection of these sites has been discussed by Fong *et al.* (1982), Sustar (1982), and others. Essentially, the sites were high-energy environments (i.e., exposed to high velocity tidal currents) and close to existing channels. It was believed that these conditions would cause disposed dredged material to disperse rapidly and eventually be exported from the Bay through the Golden Gate.

Fig. 2. Aquatic disposal sites presently used in San Francisco Bay.



Theoretically, dredged material should not have accumulated at these disposal sites. Furthermore, it was thought that by virtue of rapid dispersal and export from the Bay system most adverse potential physical and chemical impacts would be reduced, at least in comparison to the effects that might occur at a low-energy disposal site.

This has not been the case, at least for the Alcatraz site. The Alcatraz site is the site most commonly used for disposal of most of the sediment dredged within the Estuary, and a site that has been used for the disposal of construction debris, demolition debris, and other types of non-dispersable material. It was discovered in 1982 that water depths (at mean lower low water [MLLW]) at the Alcatraz site had decreased from 36.5 m to a minimum of only 8.5 m. This decrease in depth was due to mounding of disposed material. At that time, portions of the site were re-dredged in order to increase water depths. However, the mounding occurred again in 1985, and the USCOE introduced additional requirements to attempt to address the problem. These included requirements for dredgers to distribute dredged material more evenly at the disposal site, to dispose all material in a slurried state, and to submit post-project reports of dredging amounts (BCDC, 1988a).

The Alcatraz disposal site was surveyed in 1987 (SAIC, 1987b). That survey showed that between 2 and 3 million yd^3 (1.5 to 2.3 million m^3) capacity remained at the site, assuming an average minimum allowable water depth of 13.7 m at MLLW. Since that time, about 6 million yd^3 (4.6 million m^3) of dredged material have been disposed at the Alcatraz site. Additional surveys (June 1988) showed that mounding of the more recently disposed material has been minimal; site capacity is considered to be unchanged from that reported in early 1987 (SFBRWQCB, 1988). Clearly, the amount of dredged material which may be disposed of at Alcatraz is a function of the degree of future dispersal, which defines the rate of mounding. This in turn depends largely upon the nature of the material disposed.

Different authorities have made rather different estimates of the capacity of the Alcatraz site. BCDC (1988A) considered that between 5 and 20 million yd^3 (3.8 and 15.3 million m^3) may be accepted at the site, while SFBRWQCB (1988) quoted figures of 16 to 24 million yd^3 (12.2 and 18.3 million m^3). However, both these authorities agreed that there was a need to consider alternative sites for the disposal of dredged sediment from the Estuary.

In addition to the mounding of material at the Alcatraz site and its uncertain capacity to accept dredged material at the rate that disposal occurs, much debate exists on the impacts of within-Bay disposal of dredged material on biological resources. The debate does not involve the question of whether dredged material may kill individual organisms directly. Instead, the debate focuses on questions of whether localized physical impacts of dredged material disposal (e.g., turbidity and habitat alteration) have regional consequences and whether chemical contaminants associated with disposed dredged material are likely to affect Bay-wide resources.

The physical impacts of the disposal of dredged material include 1) the burial of benthic organisms by material disposed at the various sites; 2) the alteration of habitat substrates in the Estuary due to sediment resuspension and transport of large

quantities of disposed sediments to other portions of the Estuary; and 3) the creation of plumes of suspended solids (during both dredging and disposal) which may affect organisms by any of a variety of mechanisms (e.g., suffocation, habitat alteration, oxygen depletion, or burial [Sherk and Cronin, 1972]). All of these questions will be addressed in subsequent sections of this report.

In terms of chemical impacts, it is widely known that sedimentary deposits in the vicinity of urban-industrial centers like San Francisco contain measurable concentrations of many contaminants, including metals, metalloids and those organic contaminants that have an affinity for particulate matter and organic matter (MacLeod *et al.*, 1981; O'Connor *et al.*, 1982; Bieri *et al.*, 1986; see Section V.B., below). Whether chemical contaminants associated with sediments are available to the biota, and whether the dredge/disposal process can mobilize such contaminants and make them bioavailable is a complex question that has not been answered fully, and is subject to different interpretations (Rubinstein *et al.*, 1983; O'Connor, 1984). Nonetheless, the process of dredging and disposing sediments in the Estuary will certainly result in changes in the distribution of sediment-associated contaminants in the Estuary, and is a subject of great concern. For this reason, subsequent sections of this report will pay particular attention to developing the current status and possible future trends of contaminants - and contaminant effects - that may be associated with sediments and dredged materials in the Estuary.

These various problems surrounding the present practice of in-Bay disposal of dredged material have led to much discussion about the potential lifetime of existing disposal sites in the Estuary and the environmental acceptability of in-Bay disposal in general. A variety of future strategies could be applied to dredged material disposal and the selection of future disposal sites. If the existing disposal site at Alcatraz has a limited lifetime, or if current disposal practices produce unacceptable environmental effects, decisions will soon be required on alternative disposal site locations and alternative strategies for dredged material disposal. For example, the SFBRWQCB has recently adopted a dredged material disposal strategy that limits the time over which "new-work" dredged material may be disposed at the Alcatraz site and the San Francisco District of the USCOE has recently initiated a series of workshops to investigate the details of alternative dredged material disposal strategies.

D. CONTENTS AND STRUCTURE OF THIS REPORT

Part One of this report is concerned with **Dredging and Dredged Material Disposal** in the San Francisco Estuary. **Part Two** deals with issues having to do with **Waterway Modification** in the Estuary, especially in the Delta.

The remainder of **Part One** is divided into several sections, each dealing with specific aspects of the issues to be covered. **Section III** is concerned with the existing management structure relating to dredging. Relevant legislation is discussed, and the roles of the agencies involved in these areas are defined. **Section IV** deals with historical trends in dredging. Emphasis is given to information on recent trends in the dredging and disposal of dredged material; these are both better-characterized and thought to be of greater relevance to the present situation than are older data. **Section V** discusses the current status of dredging and dredged material disposal in the Estuary. This section uses the most recent data and discusses major issues in

each area. The amounts and derivations of material most recently dredged in the Estuary are included, as are the data on the quality of dredged material, its fate in the Estuary, and its possible effects on water quality and biota of the Estuary.

Section VI discusses future trends, management options, and gaps in understanding related to dredging and dredged material disposal. The management options listed are those provided by the Subcommittee on Dredging and Waterway Modification. Readers are referred to the Disposal Management Program of the US Army Corps of Engineers (Nybakken *et al.*, 1984; Ogden Beeman & Associates, 1988a, 1988b; Parr *et al.*, 1988a, 1988b; USCOE, 1988a, 1988b) for a more detailed treatment of alternate disposal strategies for the Estuary. Detailed material relating to several of the items covered in the text is provided in **Appendices**.

III. THE EXISTING MANAGEMENT STRUCTURE

This Section describes the general jurisdiction of each of the government agencies that regulate dredging and dredged material disposal activities in the San Francisco Estuary, and the roles of other government agencies and interest groups that influence management decisions and policies related to dredging activities.

A. PRINCIPAL REGULATORY AGENCIES

1. U.S. Army Corps of Engineers

From the 1820s to the present, the U.S. Army Corps of Engineers (USCOE) has had primary responsibility for maintaining navigable waters in the U.S. (OTA, 1987). Congress first assigned USCOE the task of developing and improving harbors and navigable waterways in the *General Survey Act* of 1824. The *River and Harbor Act* of 1899 directed the USCOE to issue permits for dredging activities affecting navigable waters. Sections 9 and 10 of this Act call for the USCOE to regulate diking, filling, placement of structures, or other work in these waters.

From 1899 until the late 1960s, the USCOE's review of proposed dredging activities considered only the impacts of proposed activities on navigation. In 1968, the USCOE expanded its reviews to consider impacts on fish and wildlife, conservation, pollution, aesthetics, and the general public interest (USCOE, 1968). The *National Environmental Policy Act (NEPA)* of 1969 required environmental assessment of each permit application and the preparation of an environmental impact statement where the assessment indicated significant environmental effects (Engler and Mathis, 1989).

In 1972, two laws were enacted that were specifically intended to prevent adverse environmental impacts caused by the disposal of dredged sediment to aquatic environments. Both assigned the USCOE primary authority to regulate dredging and disposal activities. Section 404 of the 1972 amendments to the *Federal Water Pollution Control Act* (or *Clean Water Act*) gave the USCOE authority to issue permits for discharge of dredged material into inland and near-coastal waters of the United States. Applicants for permits are required to satisfy several conditions intended to prevent "unacceptable adverse effects" on the aquatic environment. Ultimately the USCOE issues or denies a permit based upon a broad review of whether a project is "in the public interest." Part of such a review is the requirement that the USCOE ensure that over 30 Federal environmental laws, Executive Orders, and other stipulations have been addressed wherever applicable. Economic benefits and costs of a proposed activity must also be considered in the analysis of each application (Engler *et al.*, 1988a). Dredging activities by the USCOE itself are not covered by permits, but they are subject to the same environmental reviews as permitted dredging projects, including water quality certification by the Regional Water Quality Control Boards (see below).

Section 103 of the *Marine Protection, Research, and Sanctuaries Act* (*MPRSA*) of 1972 gave the USCOE permitting authority over the transportation of dredged material for dumping into coastal waters and the open ocean, and required reviews of the effects of proposed activities (Engler and Mathis, 1989).

The USCOE solicits comments on permit applications through a public review process. A Public Notice is distributed to all known, interested parties, including governmental agencies and other organizations. Several governmental agencies are responsible for reviewing and providing comments on permit applications, including the U.S. Environmental Protection Agency, the California Regional Water Quality Control Boards, the San Francisco Bay Conservation and Development Commission, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the U.S. Coast Guard, the California Department of Fish and Game, and the State Lands Commission. The roles of these agencies are described below.

Nationwide, the USCOE annually dredges about 380 million yd^3 (290 million m^3) for maintenance of existing channels, and about 100 million yd^3 (80 million m^3) in new work dredging, including the deepening of old channels and the excavation of new channels. The network of navigation channels created and maintained by the USCOE extends 25,000 miles in 42 states. Each year, the USCOE reviews from 10,000 to 30,000 applications for dredging permits. Dredging by permittees accounts for another 100 to 150 million yd^3 (80 to 115 million m^3) of sediment annually (Francingues *et al.*, 1985).

2. U.S. Environmental Protection Agency

The *Clean Water Act* and the *MPRSA* also assign to the U.S. Environmental Protection Agency (USEPA) a major role in the management of dredged material. Section 102 of the *MPRSA* grants USEPA authority to designate ocean disposal sites. Although the *NEPA* does not require that USEPA prepare an Environmental Impact Statement (EIS) for ocean disposal site designation, USEPA voluntarily prepares one. USEPA requires that this EIS contain a full characterization of alternative disposal sites, including an assessment of environmental conditions and potential environmental impacts at each site. USEPA is the lead agency in preparation of the EIS; the USCOE, however, conducts the environmental studies. In general, sites are to be selected that minimize effects on fisheries, navigation, and water quality. Where feasible, designated sites are located beyond the edge of the continental shelf, or at sites that have been used in the past. Section 102 further provides that USEPA manage ocean dumping sites. Under this authority, USEPA reviews permit applications to determine compliance with ocean dumping criteria, develops monitoring programs to evaluate impacts at the disposal site, and can recommend modifications for use of the site. Under Section 103 of the *MPRSA,* USEPA is required to cooperate with USCOE in the development of criteria for evaluation of environmental impacts of proposed disposal activities (USEPA, 1977; these criteria are discussed in detail in Section V.B. of this report).

Section 404 of the *Clean Water Act* requires that USEPA perform similar functions in regulation of dredging activities in estuaries and other inland waters. USEPA, in cooperation with the USCOE, has developed guidelines for evaluation of the environmental impacts of dredged material discharges in waters of the U.S. (USEPA, 1980). Section 404 also assigns USEPA the responsibility of reviewing permit applications and providing comments to the USCOE. USEPA may prohibit the

use of a particular disposal site, or restrict its use, if it is determined that disposal at the site would have unacceptable adverse environmental effects.

3. State Water Resources Control Board and Regional Water Quality Control Boards

The State Water Resources Control Board (SWRCB) and its nine Regional Boards regulate water quality in California. The Regional Boards conduct planning, permitting, and enforcement activities under the guidance and direction of the SWRCB. The San Francisco Estuary lies within the jurisdiction of the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB), which regulates water quality in the watershed of the Bay (downstream of Chipps Island), and the Central Valley Regional Water Quality Control Board (CVRWQCB), which regulates water quality throughout the Central Valley, including the Delta.

Activities affecting water quality are evaluated by the State and Regional Boards to determine if they can meet requirements established by several State plans and policies. These include: 1) Water Quality Control Plans (or Basin Plans), which are developed by each Regional Board for their specific region; 2) the Policy for The Enclosed Bays and Estuaries of California; 3) the Policy with respect to Maintaining High Quality Water in California (or Antidegradation Policy); 4) the Policy for Sources of Drinking Water; and 5) the proposed Pollutant Policy Document for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. The Policy for Enclosed Bays and Estuaries was adopted in 1974, and singled out the San Francisco Bay/Delta as an ecosystem in particular need of protection. Consequently, the Policy required that the Regional Boards implement programs that reduce contaminant discharges to the maximum extent practicable, and that disposal in the Estuary be evaluated under federal ocean dumping criteria. Recently, the State and Regional Boards have begun to develop more restrictive dredging policies. In 1987 the SWRCB commenced proceedings (known as the "Bay-Delta Hearings") to develop water quality objectives to provide protection of beneficial uses of the Estuary and consider alternate allocations of water rights to achieve such objectives. The Draft Pollutant Policy Document (SWRCB, 1988) was a preliminary product of this hearing process. One of the policies receiving consideration in the Pollutant Policy Document as a result of evidence received in the first phase of the Hearings was the prohibition of dumping of dredged material that has the potential to cause adverse impacts on the Bay's resources (SWRCB, 1988).

The SFBRWQCB recently revised their dredging policy in response to growing concern over the potential impacts of dredged material disposal in the Bay. Beginning in 1980, the SFBRWQCB's stated policy was to defer to the USCOE for dredged sediment regulation in the region. The 1986 revisions to the SFBRWQCB Basin Plan stated their intent to revise this policy. In July 1989, the SFBRWQCB adopted a policy that prohibits the disposal of material from major new work dredging projects at existing disposal sites, sets annual and monthly limits on the amounts disposed at each site, prohibits disposal at certain times when a potential exists for conflict with other beneficial uses and encourages ocean and land disposal wherever possible.

As part of the environmental review specified by the *Clean Water Act*, Section 401 requires state water quality agencies to verify that a dredged material discharge

will not violate water quality standards. This process is known as "Water Quality Certification." The Regional Boards grant Water Quality Certification for dredging and disposal activities in the San Francisco Estuary. Decisions to grant Water Quality Certification are based upon assessments of the potential for dredging and dredged material disposal to result in violations of water quality objectives. Since the Regional Boards establish these water quality objectives, they have the ultimate authority to determine the degree of contamination that results from dredging and disposal activities. The Regional Boards also have the independent authority to require whatever chemical or biological tests they consider appropriate to assess the potential for violation of water quality objectives due to dredging activities. The Regional Boards also have authority under the *California Water Code* to regulate discharges of dredged material. This regulation may take the form of "Waste Discharge Requirements" or other orders (SFBRWQCB, 1988).

4. San Francisco Bay Conservation and Development Commission

The State *McAteer Petris Act* (1965) created the San Francisco Bay Conservation and Development Commission (BCDC), and gave it permitting authority for dredging and filling activities in San Francisco Bay. BCDC expresses the policies and findings that are used in considering permit applications in the San Francisco Bay Plan (Bay Plan). BCDC also derives authority from the federal *Coastal Zone Management Act* (*CZMA*) of 1972, which specifies that federal activities (including dredging and disposal) within the coastal zone must be consistent with state coastal zone management programs to the "maximum extent practicable." BCDC's Bay Plan was the first coastal zone management program in the nation to be certified under the *CZMA*. In a process known as "consistency determination," BCDC reviews all proposed federal activities, licenses or permits to ensure compliance with the Bay Plan. In 1986, BCDC for the first time found a proposed federal dredging project (by the U.S. Navy at Hunter's Point) to be inconsistent with the Bay Plan. This determination was based on a lack of data on dredged sediment toxicity.

BCDC's goal is to preserve the resources of the Bay while providing public access to the Bay and fostering development that requires a waterfront location and is compatible with Bay protection. BCDC only allows in-Bay disposal of dredged material if no other alternatives are feasible. Further, it requires that dredged material be disposed in designated locations where a maximum amount of material is swept from the Bay by tides.

5. State Lands Commission

The State Lands Commission (SLC) administers public trust lands in coastal waters (within a three-mile state territorial limit) and other tidal and submerged areas. These lands are held in trust by the State, subject to a public easement for certain water-dependent purposes, such as waterborne commerce, navigation, fisheries, recreation, and ecological study and preservation. Written authorization from SLC must be obtained prior to dredging or depositing dredged material on lands under SLC jurisdiction. This authorization can take the form of either a dredging permit or a mineral extraction lease. Dredging permits are issued in cases where the dredged material is not used for commercial purposes. Mineral extraction leases are issued to authorize dredging for commercial purposes. Both dredging and mineral extraction

projects are reviewed for compliance with the requirements of the *California Environmental Quality Act.*

B. OTHER GOVERNMENTAL AGENCIES

1. U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (USFWS) reviews dredging permit applications and provides comments to the USCOE on the effects of proposed activities on fish and wildlife habitat. Under the *Fish and Wildlife Coordination Act* of 1958, USFWS must be consulted on federally funded, licensed, or permitted projects in any U.S. water body. In addition, USFWS has authority under the *Endangered Species Act* to control activities that may affect the habitat of endangered or threatened species. USFWS also reviews federally authorized activities pursuant to several other pieces of legislation, including the *NEPA* , the *CZMA*, the *Clean Water Act*, and the *MPRSA.* In review of proposed dredging and dredged material disposal activities, USFWS follows guidelines published in the *Federal Register* (USFWS, 1975).

2. National Marine Fisheries Service

The National Marine Fisheries Service (NMFS) has authority under the *Fish and Wildlife Coordination Act,* the *Clean Water Act*, and the *NEPA* to review federal projects that may affect marine, estuarine, and anadromous fisheries. NMFS advises the USCOE of potential adverse effects to fish habitat; in cases where effects are considered likely, NMFS either denies the permit or recommends ways to mitigate effects.

3. U.S. Coast Guard

The U.S. Coast Guard (USCG) reviews proposed dredging activities to assure that they will not impair the safe and orderly flow of maritime traffic at the sites of dredging and disposal. The USCG requires that applicants for dredging permits specify the timing, location, and nature of activities and provides this information to local mariners. USCG assists the USCOE in monitoring the activities of disposal barges in the Estuary through their "Vessel Traffic System." Under the *MPRSA*, the USCG is charged with surveillance of ocean dumping.

4. California Department of Fish and Game

Under the authority of the *Fish and Wildlife Coordination Act* , the California Department of Fish and Game (CDFG) provides comments and recommendations to the USCOE regarding the impacts of proposed dredging projects on fish and wildlife. In addition, CDFG is designated as the State's trustee agency for fish and wildlife by the State Fish and Game, Public Resources, and Water Codes, and provides comments and recommendations on documents prepared in response to the requirements of the *California Environmental Quality Act* and the *NEPA*. CDFG also administers the provisions of State and Federal *Endangered Species Acts*; the recent listing of the Chinook salmon winter run may require the application of these pieces of legislation. CDFG authority to influence the management of dredging or disposal of dredged material in the ocean stems from the *California Coastal Act* of 1976 and the

MPRSA. CDFG also participates in the development of policies and key decisions by the Regional Water Quality Control Boards and the BCDC.

5. California Coastal Commission

The California Coastal Commission (CCC) administers the provisions of the *CZMA* for coastal zones outside of the Bay region (as described above, BCDC administers *CZMA* provisions for San Francisco Bay). The CCC performs functions similar to those of BCDC, ensuring that federally authorized activities are consistent with the California Coastal Management Program. The CCC has authority to review the designation of dredged material disposal sites in the ocean.

6. Local Governments

Local governmental agencies also have jurisdiction over some types of dredged material disposal activities. For example, upland disposal sites in the portion of the northern Delta that lies within the boundaries of Sacramento County would be classified as "waste management units" under California law. The establishment of new waste management units would require that the County grant discretionary land use entitlements.

C. USER ORGANIZATIONS

As mentioned above, the USCOE solicits public review of proposed dredging activities through distribution of Public Notices. Environmental Impact Statements prepared for proposed federal projects that may have significant environmental effects (recent examples are the USCOE's Oakland Harbor Project and the U.S. Navy's *USS Missouri* Homeporting project) are also subject to public review. A wide variety of organizations representing specific interest groups are active participants in these public review processes.

Many environmental groups, including the Audubon Society, Citizens for a Better Environment, the Oceanic Society, the Pacific Coast Federation of Fishermen Association (PCFFA), Save San Francisco Bay Association, and United Anglers comment on the potential environmental effects of proposed activities. As an example of an issue of concern to these organizations, we cite the issue of the effects of disposal-derived turbidity at the Alcatraz disposal site (see comments to the Oakland Harbor Supplemental EIS [USCOE, 1988a]). Sport and commercial fishermen using San Francisco Bay suspect that disposal at the Alcatraz site causes increased turbidity in Central Bay, and that the turbidity has had an adverse effect on fishing success. Their concern, expressed through PCFFA and United Anglers, and supported by other environmental organizations and government agencies, has had a strong influence on recent policy developments. Other issues of concern to environmental organizations include the potential effects of toxic contaminants released during dredged material disposal and the locations of dredged material disposal sites.

Representatives of organizations that depend on dredging to maintain navigable channels, such as ports, marinas, other commercial enterprises dependent on waterborne transportation, yachting associations, and the U.S. Department of Defense, also provide comments on dredging management decisions and policies.

Examples of such organizations include the Golden Gate Ports Authority, the Pacific Interclub Yachting Association, the Port of Oakland, and the U.S. Navy. These organizations typically express concern over the costs or other constraints associated with restrictions on dredging activities.

These user organizations often enter into litigation in efforts to influence management decisions or policies that they consider to be inconsistent with applicable environmental legislation and policies. As a recent example, a Supplemental Environmental Impact Statement on the proposed ocean disposal of material to be dredged in the deepening of Oakland Harbor (USCOE, 1988a) has prompted several lawsuits. Citizens for a Better Environment filed a successful lawsuit against the Port of Oakland, arguing that the Port had not followed the provisions of the *CEQA*. The Half Moon Bay Fishermen's' Marketing Association then filed an unsuccessful suit against the USCOE and the Port of Oakland, asserting that in selection of an ocean disposal site they had failed to satisfy the requirements of the *NEPA*, the *Fish and Wildlife Coordination Act*, and the *CEQA*. Finally, ocean disposal of the Oakland Harbor material was postponed due to a lawsuit filed by the County of San Mateo, which argued that the USCOE had violated provisions of the *California Coastal Act*. The Oakland Harbor Project has also prompted legal dispute between government agencies; the question of the CCC's authority in designation of disposal sites beyond the three-mile state territorial limit is currently under litigation between the USCOE and the CCC.

IV. HISTORICAL TRENDS

A. LOCATION, CHARACTERISTICS, AND MAGNITUDE OF DREDGING

This Section reviews historical trends in dredging and dredged material disposal in the Estuary, beginning with an account of human influences on sedimentation patterns and the origins of dredging and disposal of dredged material in the Estuary. A detailed discussion of long-term trends in dredging is then provided, based on the most reliable data available. The magnitude of dredging projects and disposal at different sites in the Estuary and the adjacent ocean is also evaluated.

1. The Origins of Dredging Activities

Historical accounts of the San Francisco Bay and Delta describe riparian forests, extensive salt and freshwater marshes, swamps, grasslands, savannahs, and a labyrinth of channels surrounding the open waters of the Bay (Margolin, 1978). Since then the area has been altered substantially by human activities. The discovery of gold in the Sierra Nevada foothills in 1848, the reclamation of land in the Delta and on the margins of the Bay, and the agricultural development of the Central Valley have had a variety of effects, including: 1) increased sediment loading due to processes used to extract ore (and, more recently due to agricultural runoff); 2) the filling and diking of marshlands and tidal areas for agricultural, industrial, and urban uses; and 3) the dredging of channels, turning basins, slips, and marinas for commercial shipping and recreational boating.

Hydraulic mining technology for gold began in 1853 and resulted in the annual excavation of tens of millions of cubic yards of sediments and rock. These sediments and mashed rock were washed downstream, resulting in the deposition of massive quantities of sedimentary debris in creeks and rivers and the obstruction of navigation channels throughout the drainage basin (Gilbert, 1917; USCOE, 1975b). During spring and winter runoff, the obstructed channels overflowed, causing periodic and massive flooding (Nichols *et al.*, 1986). This excess sedimentary material was eventually transported to the Bay and Delta, causing alterations of such magnitude that hydraulic mining technology was prohibited by court injunction in 1884 (USCOE, 1975b; Nichols *et al.*, 1986).

Long-term changes in Estuarine sedimentation patterns were produced by this increased sediment loading. For example, Southhampton Bay (in Carquinez Strait) experienced a loading of 300,000 yd^3 (229,000 m^3) yr^{-1} between 1857 and 1886. This rate gradually decreased subsequent to the cessation of hydraulic mining in the basin; during the period 1922 and 1940, the loading had decreased to 43,500 yd^3 (33,000 m^3) yr^{-1}. In the last four decades an equilibrium state has been reached such that no net deposition or erosion of sediment occurs in Southhampton Bay (Sustar, 1982). Other areas of the Estuary also exhibited changes of this type, including Vallejo Bay (at Martinez), which was essentially obliterated by mining debris (Krone, 1979). In general, increasing sedimentation in the Estuary accelerated the geological "evolution" of the system (Schubel and Carter, 1977), reducing the open water area of

the Bay and Delta, and causing mudflats to form in shallow embayments and some channels.

A second major impact of the Gold Rush was the sudden increase in the non-native human population in the Bay region, from 450 in 1847 to over 30,000 in 1849 (USCOE, 1975b). To satisfy new urban and agricultural needs, the filling of wetlands and marshes surrounding the Bay and the Delta commenced. This activity decreased the open water area of the Bay, altered natural circulation patterns and, in some cases, affected sedimentation rates.

Population growth in the Bay region led to the need for a deepwater port to provide supplies and equipment to the miners. This need led to Congressional authorization of the *River and Harbor Act* of 1868, which provided for the creation and maintenance of the first Federally authorized dredging project in San Francisco Bay (the San Francisco Channel). Other channels, anchorages, ports, and terminals were later constructed to expedite the export of grain, lumber, and petroleum products from San Francisco, thus increasing Federal responsibilities for maintaining shipping channels. The necessity of providing a reliable means of access for ever-larger vessels to the inland ports of the Bay and Delta has resulted in construction of the numerous Federally maintained channels currently in use.

2. Sites of Dredging and Historical Trends

A. GENERAL

As discussed in Section III, the USCOE grants permits for dredging projects undertaken in the Bay and Delta. The USCOE Districts in San Francisco and Sacramento are responsible for carrying out several Congressionally authorized projects, also known as "Federal" or "Civil Works" projects, in the Bay and Delta. Fourteen Federal maintenance projects of the San Francisco and Sacramento Districts, USCOE, are described below. The District Offices also regulate dredging and disposal activities by issuing permits to other dredgers. The division between the geographical responsibilities of these two Districts is in the Estuary near Antioch.

This discussion of historical trends in dredging and disposal focuses on dredging performed by the USCOE and the U.S. Navy from 1975 to 1985, the only time for which reliable data are available. Most of the data presented below were obtained from computerized databases maintained by the USCOE (1989a) and the U.S. Navy (1989). The data on dredging volumes derive from the results of bathymetric surveys performed before and after permitted dredging operations. The USCOE database (USCOE, 1989a) contains data for all San Francisco District USCOE Civil Works projects from 1975 to the present. Data prior to 1975 are available only for certain projects. Background information on the various USCOE and U.S. Navy projects was obtained from USCOE (1975b) and USCOE (1985).

The only data for projects other than the U.S. Navy are based on estimates listed in the permit applications for each project. Such estimates are only made in the planning stages of each project and tend to overestimate the amounts to be dredged. Because of the uncertainty associated with these "permitted amounts," these data were not compiled from files at the USCOE for the period of interest (1975-1985).

Reliable estimates of amounts dredged by all permittees were available for the years 1986 and 1987, as described in Section V.A. Given the fact that the volume of dredged material generated by non-Federal projects in 1986-87 was about 38% of the total volume dredged, we can only assume that a similar distribution of Federal and non-Federal dredging occurred in the past. In the New York District of the USCOE, non-Federal projects generate a fairly consistent proportion of dredged material (between 20 and 40% of the total for the Port of New York and New Jersey; New York District/USCOE, 1988); however, for 3 of the 19 years of record (1970-1988) permitted, private dredging projects generated more than 50% of the dredged material volume in the New York District (O'Connor, 1989). It is possible, therefore, that between 1975 and 1985 significant quantities of material were dredged by the private sector, although a lack of data prohibits further discussion of this topic.

B. PROJECTS IN SAN FRANCISCO BAY

The locations of the USCOE and U.S. Navy maintenance dredging projects in San Francisco Bay are shown in Figures 3 and 4; average annual amounts of material dredged in each project over the period 1975-1985 are shown in Table 1. Appendix 1 provides additional details.

Projects undertaken within the San Francisco Bay vary considerably in size and dredging frequency. Most of the dredging by the USCOE and U.S. Navy from 1975 to 1985 took place at four project sites. In descending order of the amounts dredged, these sites were:

(i) Mare Island Strait (an average of 1.49 million yd [1.14 million m^3] yr^{-1} dredged by USCOE and disposed of at Carquinez, and 617,000 yd [471,000 m^3] yr^{-1} dredged by the Navy and disposed on land);

(ii) Alameda Naval Air Station (614,000 yd^3 [469,000 m^3] yr^{-1} dredged by the U.S. Navy, and disposed of at Alcatraz);

(iii) Richmond Harbor (502,000 yd^3 [384,000 m^3] yr^{-1} dredged by the USCOE and disposed of at Alcatraz); and

(iv) Oakland Harbor (353,000 yd^3 [270,000 m^3] yr^{-1} dredged by the USCOE and disposed of at Alcatraz).

Dredging from these sites generally took place each year between 1975 and 1985. Because of their importance in determining the overall amounts of maintenance dredging occurring in the Estuary on a regular basis, these projects are discussed in greater detail below. Dredging rates of greater than 50,000 yd^3 (38,000 m^3) yr^{-1} occurred at several other sites, including Redwood City Harbor, Suisun Bay Channel, the Petaluma River, Pinole Shoal, Oakland Naval Supply Center, Point Molate Naval Fuel Depot, and San Leandro Marina. Dredging at these locations occurred intermittently from 1975 to 1985, typically once every 2 to 3 years. Dredging at other locations averaged less than 50,000 yd^3 (38,000 m^3) yr^{-1} (Table 1) and, in general, took place only once in the 11-yr period.

Fig. 3. Locations of USCOE maintenance projects, San Francisco District. After USCOE (1975b).

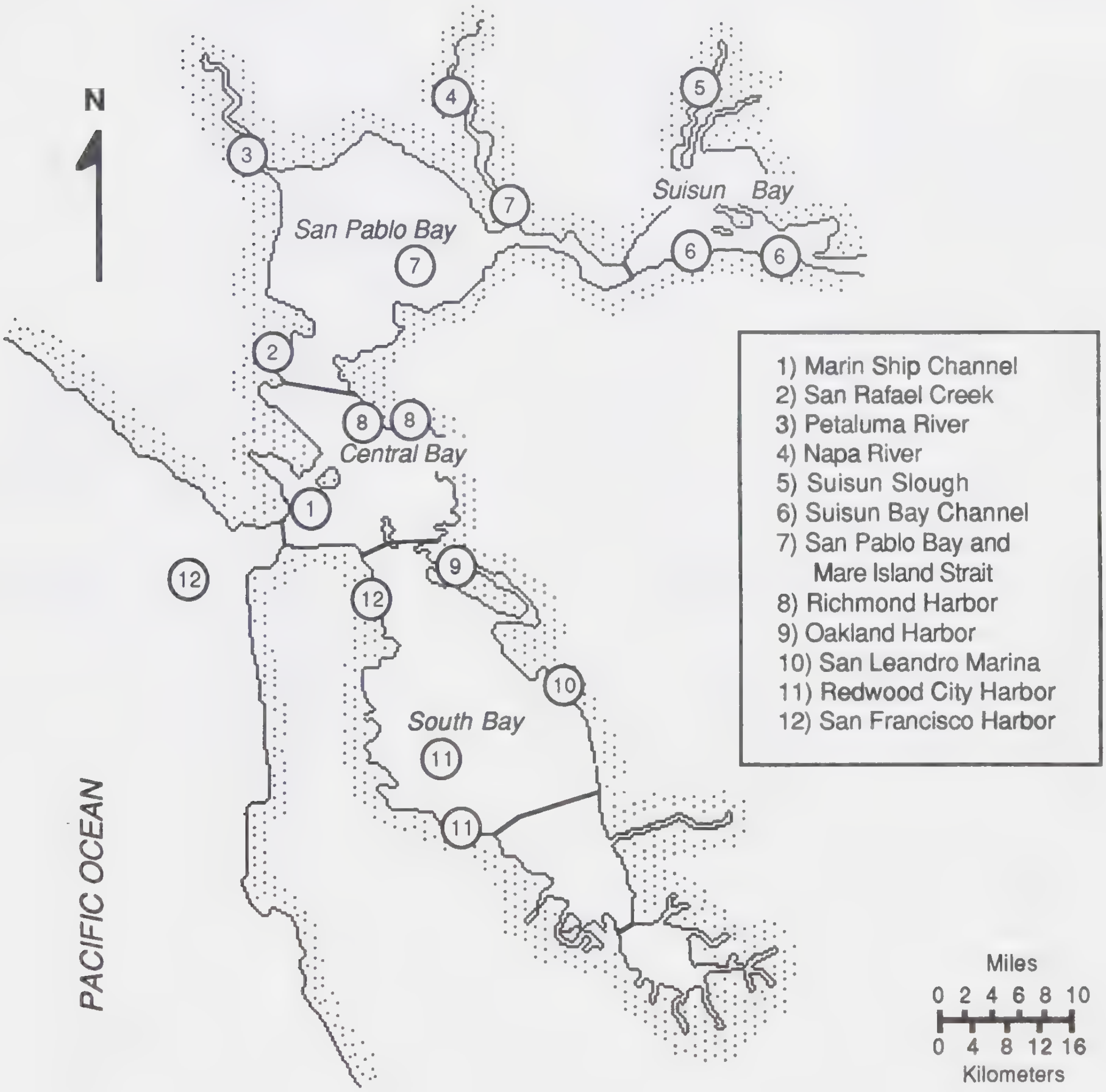


Fig. 4. Naval facilities where dredging was performed in 1975-1985. Data from U.S. Navy (1989).

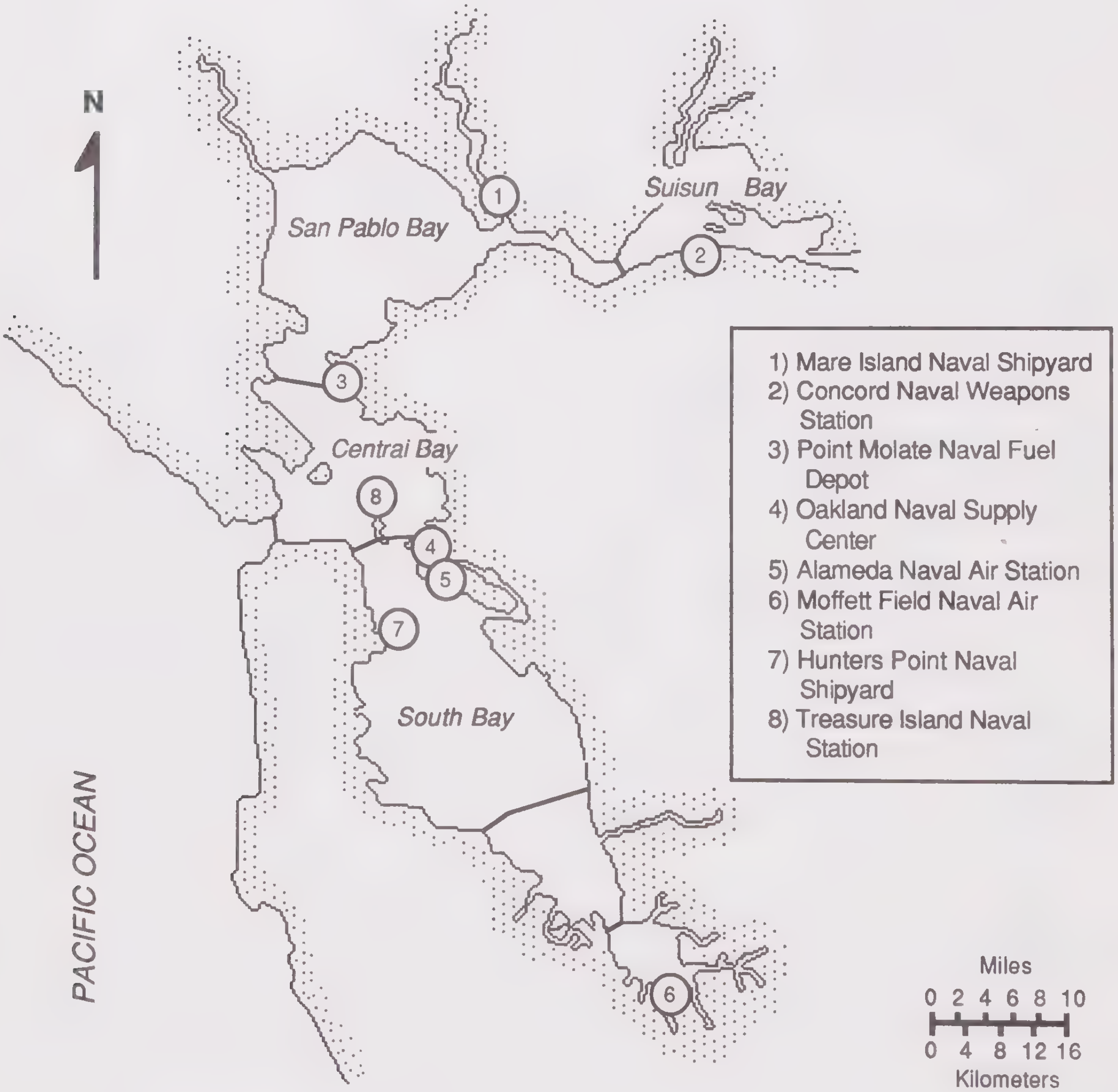


Table 1. Annual average maintenance volumes dredged (yd^3) in San Francisco Bay by the USCOE and U.S. Navy from 1975 to 1985. Projects are grouped by disposal site. Data from USCOE (1989a) and U.S. Navy (1989)

SITE	Project	Annual Average	# Yrs	Maximum	Year of Maximum
ALCATRAZ	Alameda NAS	614,000	8	1,589,000	1983
	Richmond Harbor	502,000	10	1,032,000	1984
	Oakland Harbor	353,000	11	536,000	1980
	Redwood City Harbor	121,000	3	790,000	1984
	Oakland NSC	67,000	1	740,000	1983
	Point Molate NFD	62,000	6	303,000	1984
	Islais Creek (SF Harbor)	44,000	1	487,000	1977
	Treasure Island NS	42,000	1	457,000	1985
	Hunters Point NSY	32,000	2	180,000	1983
	Marin Ship Channel	19,000	1	208,000	1982
	NAS Moffett Field	19,000	1	207,000	1979
	San Rafael Creek	14,000	1	153,000	1978
	Oakland Army Base	7,000	1	82,000	1980
	TOTAL	*1,896,000*			
SAN PABLO BAY	Petaluma River	100,000	2	601,000	1983
	Pinole Shoal	92,000	4	433,000	1984
	TOTAL	*192,000*			
CARQUINEZ	Mare Island Strait	1,490,000	11	2,347,000	1982
	Concord NWS	23,000	4	110,000	1985
	TOTAL	*1,513,000*			
SUISUN BAY	Suisun Bay Channel	112,000	8	285,000	1980
LAND	Mare Island[1]	617,000	6	876,000	1982
	Petaluma River	79,000	3	444,000	1975
	San Leandro Marina	50,000	2	297,000	1978
	Napa River	35,000	1	382,000	1981
	Suisun Slough	9,000	1	99,000	1982
	San Rafael Creek	5,000	1	52,000	1980
	Alameda NAS	3,000	2	27,000	1981
	Treasure Island NS	3,000	1	35,000	1985
	NAS Moffett Field	1,000	1	12,000	1985
	TOTAL	*802,000*			

1 Data from 1980 to 1985. Average calculated for this 6-yr period.

Mare Island Strait

Dredging at Mare Island Strait, including material disposed at aquatic disposal sites and on land, accounted for 47% of the total maintenance dredging activity in San Francisco Bay between 1975 and 1985. Most of the dredging at Mare Island Strait was performed by the USCOE as part of the San Pablo Bay Project. The existing project was authorized by the *River and Harbor Act* of 1927. Significant year-to-year differences in the total amounts dredged from Mare Island Strait are evident (Fig. 5[a]), with the smallest volumes dredged in 1977 and 1985. All material dredged from Mare Island Strait by the USCOE (about 1.5 million yd^3 [1.15 million m^3] annually) was disposed at the Carquinez Strait disposal site. Beginning in 1980, the U.S. Navy dredged an additional 617,000 yd^3 [472,000 m^3] yr^{-1} at Mare Island and disposed of this material in containment areas on the Island.

Alameda Naval Air Station

Alameda Naval Air Station is a major berthing area for large ships of the Pacific Fleet and is located near the entrance to Oakland Harbor. Substantial dredging at the Alameda Naval Air Station began during World War II. Dredging at the Alameda site occurred at an average rate of 614,000 yd^3 (469,000 m^3) yr^{-1} between 1975 and 1985. Figure 5(b) shows annual trends in amounts dredged during this period. The greatest amount was dredged in 1983 (1.6 million yd^3 [1.2 million m^3]).

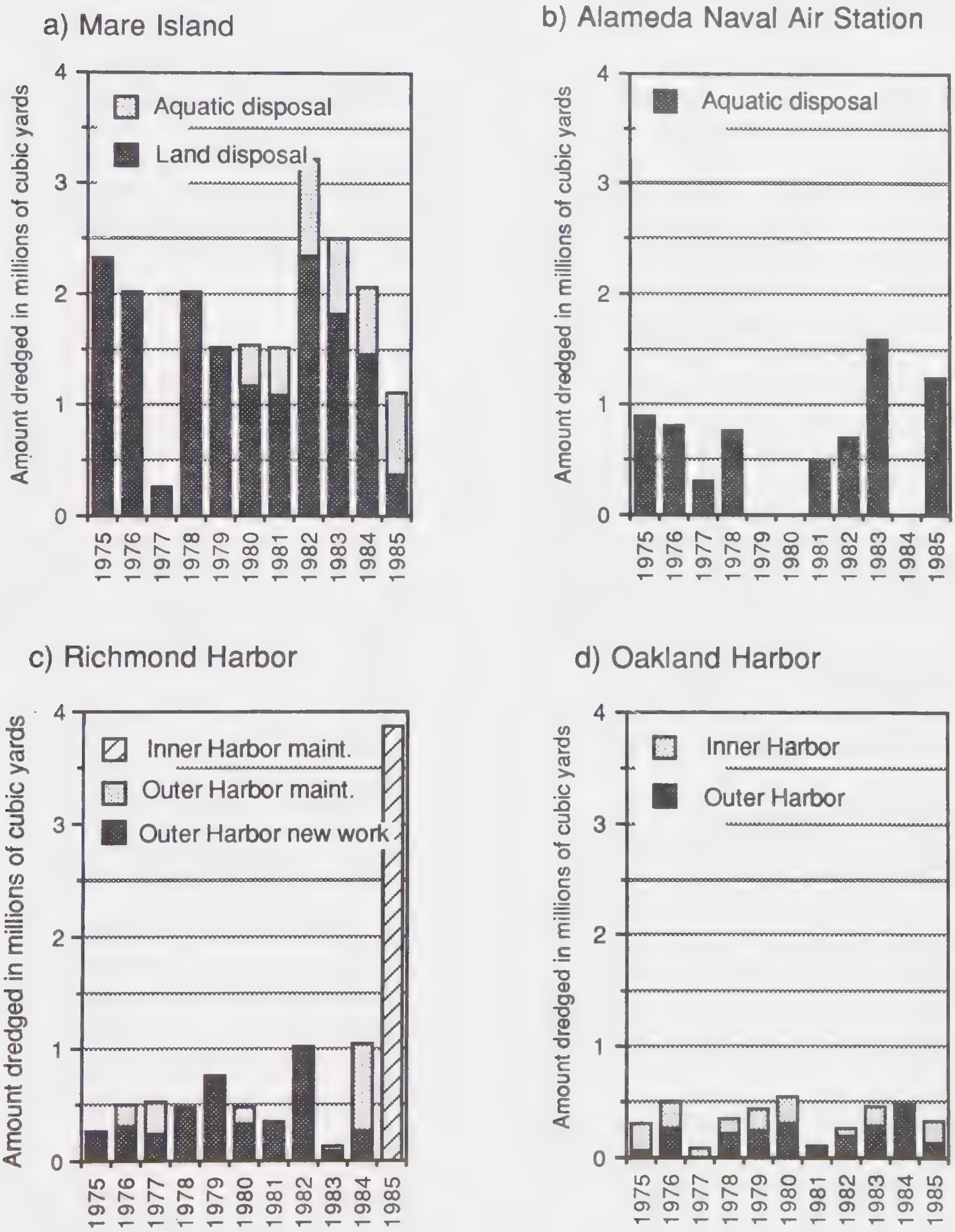
Richmond Harbor Project

The Richmond Harbor Project was authorized by the *River and Harbor Act* of 1917 and has been modified several times since. Two channels exist, one in the Inner Harbor, the other in the Outer Harbor. An average of 502,000 yd^3 (384 million m^3) yr^{-1} was dredged in maintenance of Richmond Harbor from 1975 to 1985. An additional 3.9 million yd^3 (3 million m^3) of new work dredging in the Outer Harbor occurred in 1985, in connection with the John F. Baldwin Project. This project continued into 1986 (see Section V.A. below). Figure 5(c) shows annual dredging rates for Richmond Inner and Outer Harbors from 1975 to 1985. The volume of new work dredging associated with the John F. Baldwin Channel Project in 1985 was comparable to all maintenance dredging in the previous 10 yr.

Oakland Harbor Project

Oakland Harbor has been dredged since 1876. The present project involves the Inner Harbor channel (13.6 km in length); the Tidal Canal (2.6 km in length); and the channel maintained for the Outer Harbor (5.4 km in length). Dredging volumes at these sites averaged 353,000 yd^3 (270,000 m^3) yr^{-1} between 1975 and 1985 . The annual amount of dredging activity each year has varied (see Fig. 5[d]), being least in 1977 and 1981.

Fig. 5. Volumes of sediment dredged annually from a) Mare Island Strait, b) Alameda Naval Air Station, c) Richmond Harbor, and d) Oakland Harbor, 1975-1985. Data from USCOE (1989a) and U.S. Navy (1989).



C. PROJECTS IN THE DELTA

The Sacramento District is responsible for two Federal maintenance dredging projects in the Delta. These are the Sacramento River Deep Water Ship Channel and the Stockton Deep Water Ship Channel. Other federally authorized projects have been constructed and maintained for various periods, but none of these were active within the last 20 yr (R. Kelly, USCOE, personal communication).

Sacramento River Deep Water Ship Channel

Construction of the Sacramento River Deep Water Ship Channel was authorized by the *River and Harbor Act* of 1899. Subsequent improvements between 1949 and 1970 removed an unknown volume of sediment to create the present Channel. An average of 352,000 yd^3 (269,000 m^3) yr^{-1} was removed to maintain the Channel between 1975 and 1985. Figure 6 shows annual trends in dredging from the Channel during this period: in certain years, no maintenance dredging occurred, but a maximum of about 1.4 million yd^3 (1.1 million m^3) was dredged in 1984 .

Stockton Deep Water Ship Channel

The Stockton Deep Water Ship Channel is one segment of the San Francisco to Stockton (John F. Baldwin) Ship Channel. The John F. Baldwin Ship Channel is a modification of the San Joaquin River Project, originally authorized in 1876. Several modifications have been authorized since that time, the most recent by the *River and Harbor Act* of 1965. The Act calls for extensive dredging, both in the area of the Channel itself and in the approaches to the Channel through San Francisco Bay. From 1975 to 1985, USCOE removed an average of 131,000 yd^3 (about 100,000 m^3) yr^{-1} of sediment in maintenance of the Stockton Deep Water Ship Channel. This dredging took place in only 3 of the 11 years of interest (Fig. 6); a maximum of 841,000 yd^3 (643,000 m^3) was dredged in 1978.

Permitted Projects

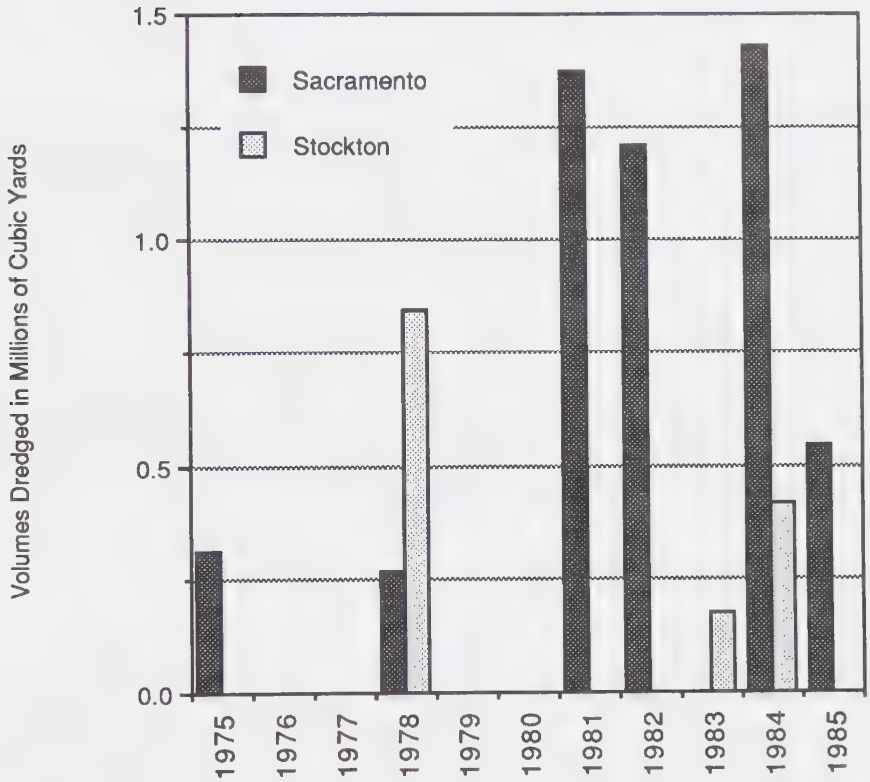
In addition to the two Federal maintenance projects discussed above, the Sacramento District of the USCOE issues permits for other dredging projects, including Federal agencies, ports, private individuals, and Reclamation Districts. Reclamation Districts dredge in order to repair and maintain their levees under the authority of a single 5-yr general permit (USCOE Public Notice GP-014); however, reliable data on the volume of material dredged by the Reclamation Districts are not available from the USCOE. Historical data on other permitted activities occurring in the Delta have apparently not been compiled by the Sacramento District Office of the USCOE, and thus are not available for review.

3. The Disposal of Dredged Material

A. GENERAL

Dredged sediment was disposed at many locations in the San Francisco Estuary prior to 1972 (USCOE, 1975b). In May 1972 USCOE Public Notice 72-61

Fig. 6. Volumes of sediment dredged annually from the Sacramento Deep Water Ship Channel and the Stockton Deep Water Ship Channel from 1975 to 1985. Data from USCOE (1989c).



designated six dredged material disposal sites in the Estuary. The six sites included five in-Bay aquatic disposal sites west of Carquinez Strait and one disposal site in Suisun Bay (Fig. 7). This action was based on the need to regulate indiscriminate dredged material dumping (USCOE, 1972).

Two of the designated disposal sites were located in the South Bay (one at Hunters Point, the other just south of the Dumbarton Bridge). The use of these two sites has been discontinued. The remaining four disposal sites are at Alcatraz, San Pablo Bay, Carquinez Strait, and Suisun Bay. In addition to the in-Bay disposal sites, two ocean sites were also designated for the aquatic disposal of dredged sediment. One of these was located in the Gulf of the Farallones in water 182 m deep (the "100-fathom site"). The second ocean site employed was the San Francisco Channel Bar (USCOE, 1975b).

The following sections review the data concerning historical disposal sites, including their location, restrictions, volumes disposed, years utilized, and their current status. Volumes of dredged material mentioned in this section refer only to the USCOE and Navy projects described in the previous Section. These figures do not account for dredging performed by permittees other than the Navy.

B. AQUATIC DISPOSAL SITES WITHIN THE BAY

The first three sites discussed, Carquinez Strait, San Pablo Bay, and Alcatraz, are currently designated for disposal of dredged material from USCOE and permitted projects. The fourth site, in Suisun Bay , is used only for disposal of sandy material excavated by the USCOE from the Suisun Bay Channel.

The Carquinez Strait Disposal Site (SF-9)

The Carquinez Strait disposal site (SF-9; Fig. 8) is located west of the Carquinez Bridge, in a rectangle 304 m wide by 609 m long, 1.4 km from the Mare Island entrance (USCOE, 1975b). Depths at SF-9 range from 8.5 to 17.1 m, and average 12.8 m (42 ft). The Carquinez site was designated by the USCOE in 1972 to receive dredged sediment under Public Notice 72-61; however, the site has been in use since about 1931 (USCOE, 1989a). SF-9 receives dredged material from Mare Island Strait, and, with the exception of dredged material from the Suisun Bay Channel and Suisun Slough projects, from all dredging projects conducted in Suisun Bay.

Between 1975 and 1985 this site received an annual average of 1.5 million yd^3 (about 1.1 million m^3) of maintenance and new work material, almost all of which came from USCOE dredging of Mare Island Strait (Table 1). Annual trends in disposal at this site are shown in Fig. 9. In 1975 the Carquinez Strait disposal site received 78,000 yd^3 (about 60,000 m^3) of sediment dredged from the Concord Naval Weapons Station that was too contaminated for disposal in Suisun Bay. As stated by the USCOE, "This material was disposed of at the Carquinez site because the levels of trace metals present in the material exceeded EPA criteria" (USCOE, 1975b). It is not clear, nor has it been explained to the authors, why dredged material that was too contaminated for disposal in Suisun Bay was acceptable for disposal at the Carquinez site.

Fig. 7. Disposal sites designated in 1972 by the San Francisco District, USCOE. USCOE (1972).

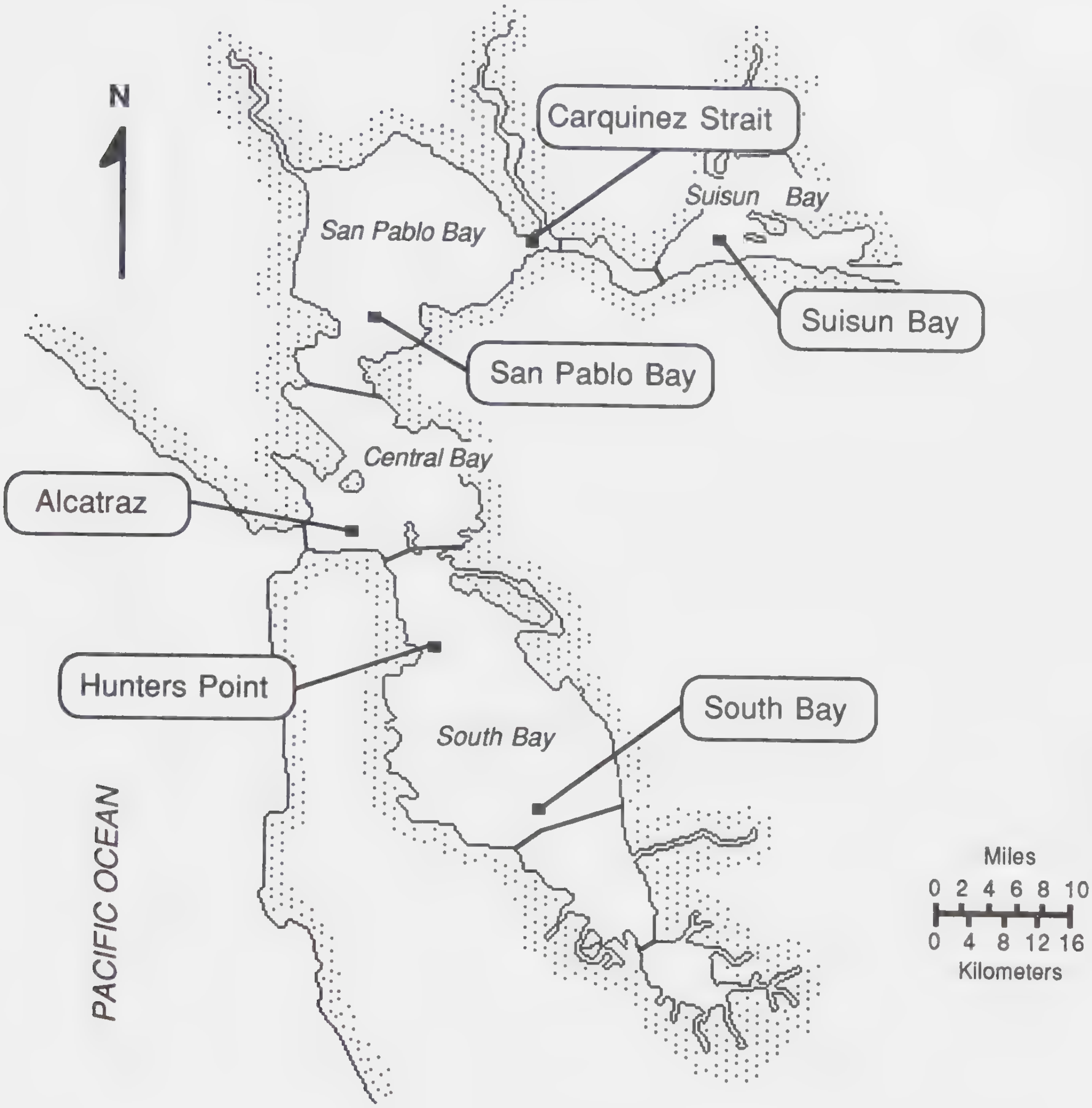


Fig. 8. Detail of the Carquinez Strait Disposal Site. From U.S. Navy (1989).

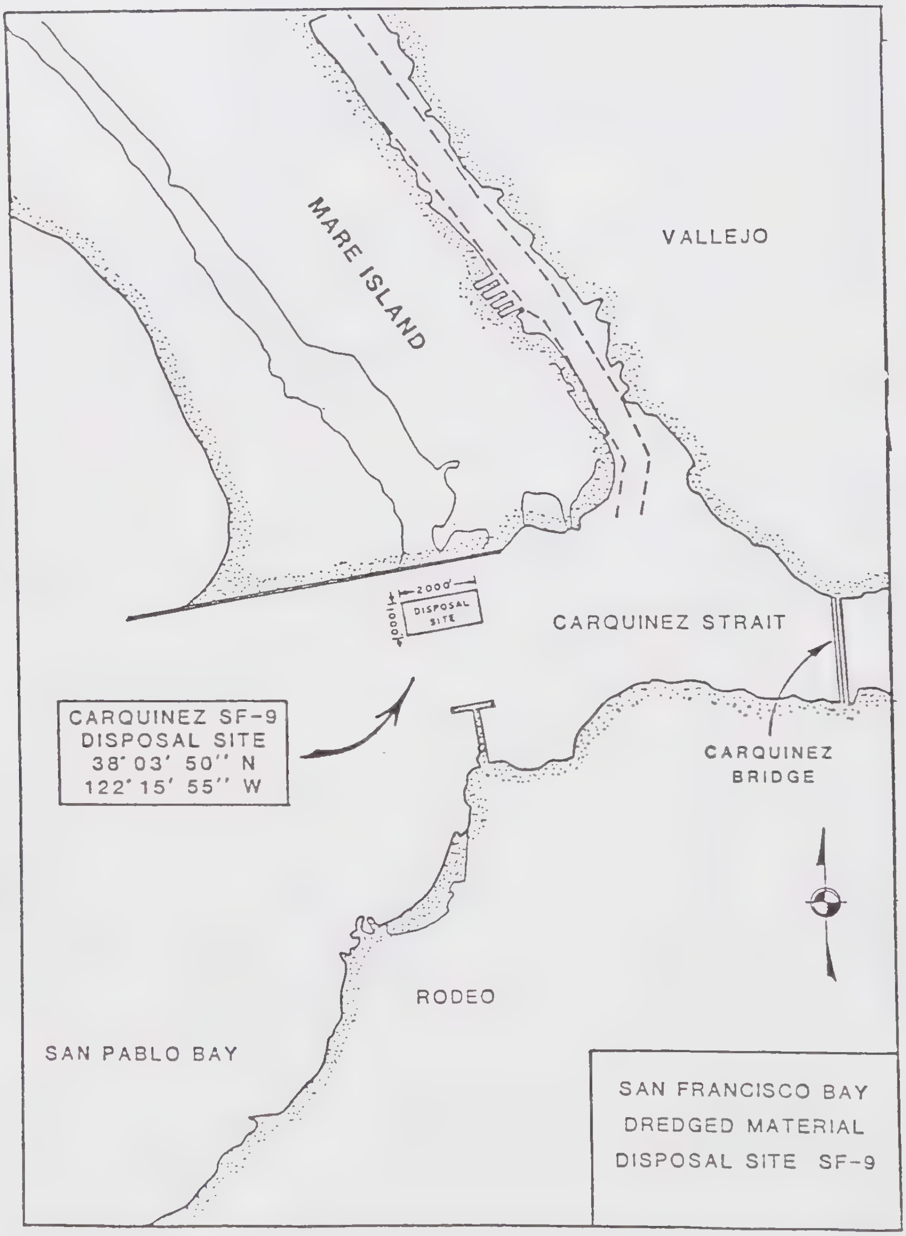
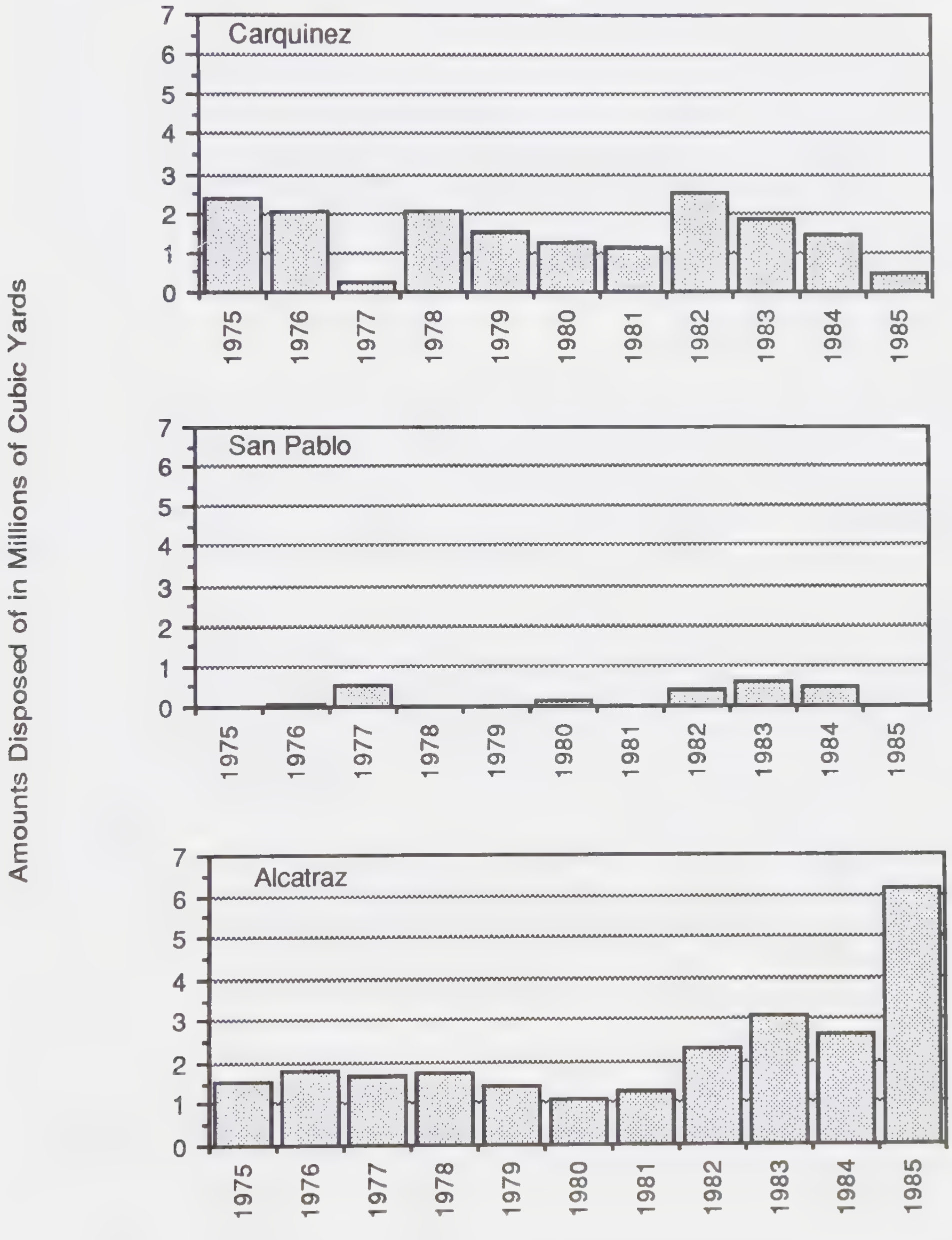


Fig. 9. Volumes of sediment from USCOE and U.S. Navy projects released annually at the Carquinez Strait, San Pablo, and Alcatraz disposal sites from 1975 to 1985. Data from USCOE (1989a) and U.S. Navy (1989).



The San Pablo Bay Disposal Site (SF-10)

The San Pablo Bay disposal site (SF-10) is a rectangular area 457 m wide by 914 m long, located 4.6 km northeast of Point San Pedro (Fig. 10). Depths at SF-10 range from 11.6 to 12.2 m, and average 11.9 m (USCOE, 1975b). Officially designated as a dredged material disposal site in 1972, the San Pablo Bay site has been used to dispose of sediment from the Pinole Shoal project since 1940 (USCOE, 1989a). The site also receives sediment dredged from the Petaluma River maintenance Project (Table 1).

The San Pablo Bay site received an annual average of 192,000 yd^3 (147,000 m^3) of dredged sediment between 1975 and 1985. This material came from USCOE maintenance projects in the Petaluma River and Pinole Shoal. Figure 9 shows the pattern of dredged material disposal at this site during the 11-yr period. The largest volume disposed of in a single year was 601,000 yd^3 (459,000 m^3; 1983). No dredged material was disposed at the site in 5 years; 1975, 1978, 1979, 1981, and 1985.

The Alcatraz Disposal Site (SF-11)

The Alcatraz disposal site is a circular area about 600 m (2000 ft) in diameter, approximately 0.5 km south of Alcatraz Island (Fig. 11). Depths originally ranged from 28.9 to 48.7 m, and averaged 39.6 m (see USCOE, 1975b). The Alcatraz site was designated to receive dredged material by the USCOE in 1972 under Public Notice 72-61. The site actually has been used for the disposal of dredged material since 1890 (Wakeman, 1988).

The Alcatraz disposal site received an annual average of 2.2 million yd^3 (about 1.7 million m^3) of dredged material from maintenance dredging and new work between 1975 and 1985. This material disposed at Alcatraz came from many projects, including large amounts from Alameda Naval Air Station, Richmond Harbor, and Oakland Harbor (Table 1). Annual trends in disposal from 1975 to 1985 are shown in Fig. 9. Disposal volumes increased beginning in 1982, primarily due to increased dredging at the Alameda Naval Air Station and Richmond Harbor. Increased disposal at Alcatraz in 1985 resulted from a new work project at Richmond Outer Harbor (3.9 million yd^3; about 3 million m^3); this dredging was performed as part of the John F. Baldwin Ship Channel project.

Suisun Bay

The Suisun Bay site lies parallel to the Suisun Bay Channel at a minimum distance of 152 m from the channel. The site is about 1 km from shore in an area 152 m wide by 3,410 m long, at a depth of about 9.1 m. Although the Suisun site was objected to by State and Federal agencies in the early 1970s, and was described as having been phased out as a disposal site in USCOE (1975b), it was still in use in 1988, receiving material dredged from the Suisun Bay Channel. An annual average of 112,000 yd^3 (about 86,000 m^3) of dredged material from Suisun Bay Channel was released at this site between 1975 and 1985.

Fig. 10. Detail of San Pablo Bay disposal site. From U.S. Navy (1989).

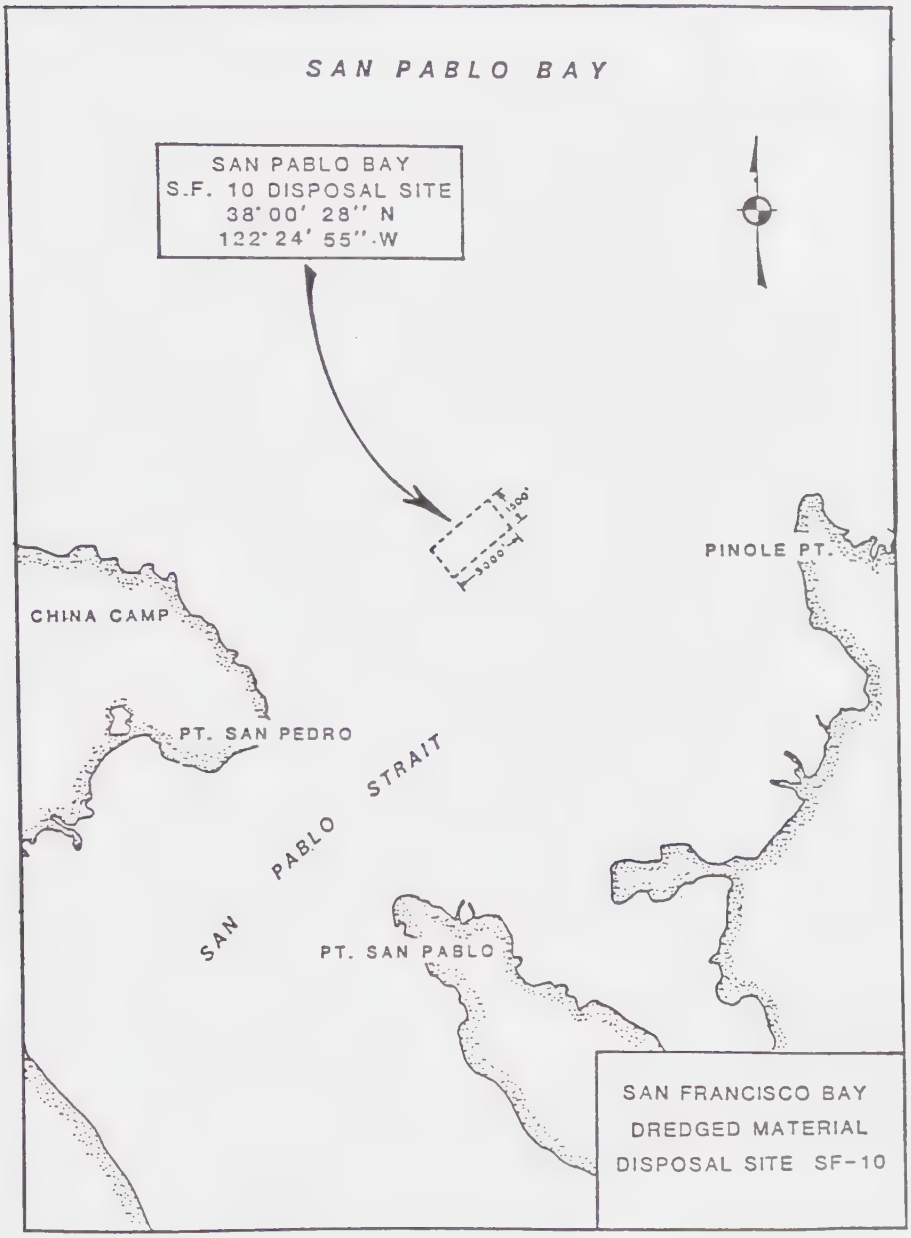
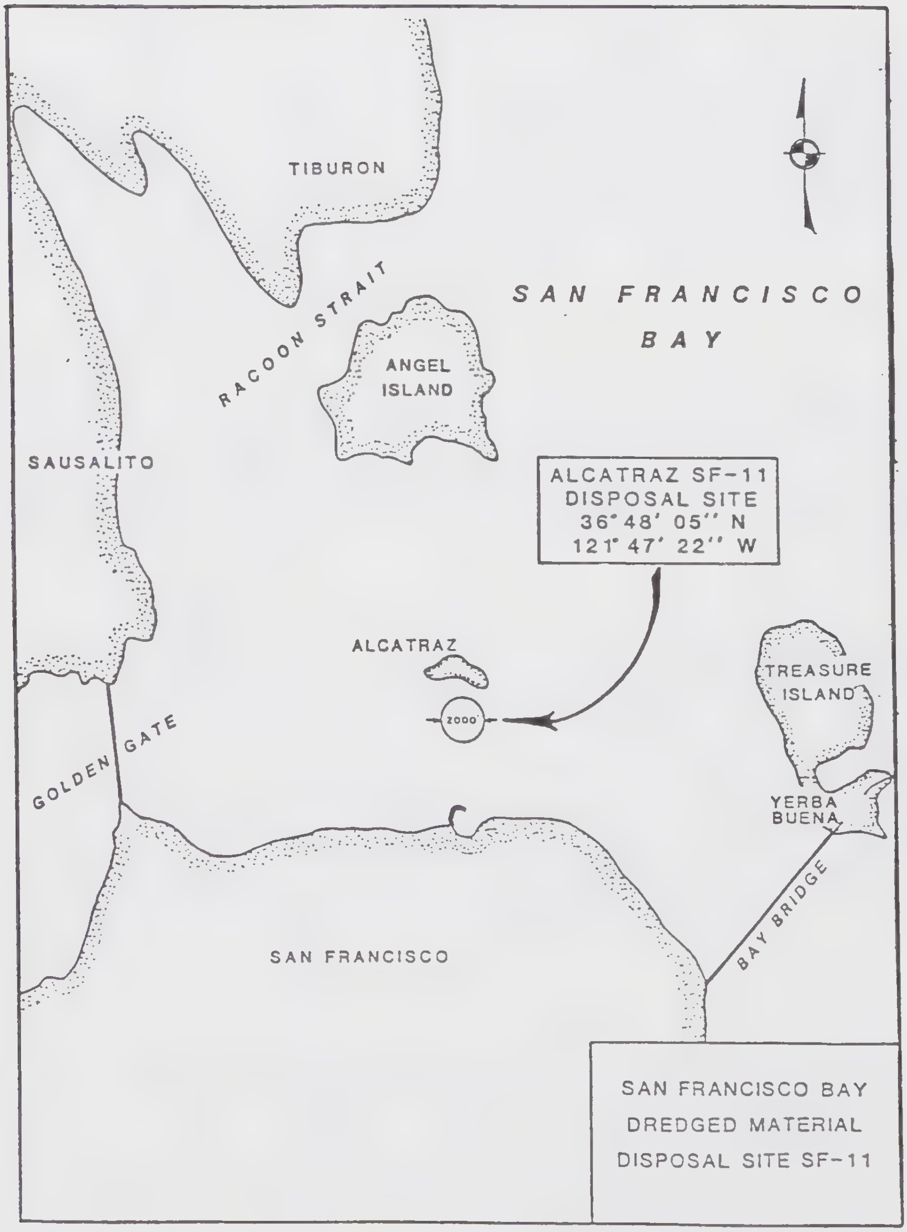


Fig. 11. Detail of the Alcatraz disposal site. From U.S. Navy (1989).



Former Aquatic Disposal Sites

Until the 1970s, aquatic disposal of dredged material took place at numerous sites in the Estuary (Table 2, Fig. 12). In addition to the sites listed in Table 2 it is known that many diked, historic baylands were filled with dredged material from the time of original Congressional authorization of dredging projects until the time disposal came under strict regulation. Some of these historic sites were Foster City, Coast Guard Island, Oakland Airport, and Alameda Island. In some cases, little information is available on disposal practices at historic dredged material disposal sites. In all cases, the disposal sites were located a conveniently short distance from the site or sites of dredging. The use of any sites other than those in San Pablo Bay, Carquinez Strait, Alcatraz, and Suisun Bay was prohibited by 1975.

The volumes of dredged material disposed at former aquatic disposal sites have not been documented in many cases. However, it is known that between 1931 and 1970, 27 million yd^3 (21 million m^3) of sediment dredged from Oakland Harbor by the USCOE were disposed at the southwest side of Yerba Buena Island (USCOE, 1975b). This was equivalent to an annual disposal rate of 700,000 yd^3 (535,000 m^3) yr^{-1}. The Yerba Buena Island site has also received dredged material from U.S. Navy projects in Oakland Harbor. A total of 12 million yd^3 (9.2 million m^3) of material dredged from the Alameda Naval Air Station between 1959 and 1975 was dumped in nearby waters, often near the entrance to the Station. Lastly, 12 million yd^3 (9.2 million m^3) of dredged material from Richmond Harbor was disposed on the east side of Angel Island from 1951 to 1971, corresponding to an average rate of disposal of 600,000 yd^3 (about 459,000 m^3) yr^{-1} (USCOE 1975b).

C. LAND DISPOSAL SITES

Until the early 1970s, marshlands were used as disposal sites for dredged material in some 11 sites around the shores of the Bay and Delta (USCOE, 1975b). Although these sites were never officially designated to receive dredged materials, they were used regularly. The sites are listed in Table 3.

A number of these land disposal sites are still used for disposal of material dredged by the USCOE and the U.S. Navy. The sites still in use are on the Petaluma River, on Mare Island, on the shore of the Napa River, at the Alameda Naval Air Station, and at the San Leandro Marina (Table 3; see Table 1 for average amounts disposed of from 1975 to 1985). The largest quantities of dredged material were disposed at Mare Island, where an average volume of over 600,000 yd^3 (459,000 m^3) was disposed each year. Other sites that received an annual average of more than 10,000 yd^3 (7,600 m^3) between 1975 and 1985 included Petaluma River (79,000 yd^3 [60,000 m^3] yr^{-1}), San Leandro Marina (50,000 yd^3 [38,000 m^3] yr^{-1}), and Napa River (35,000 yd^3 (27,000 m^3] yr^{-1}). Other sites listed in Table 3 received smaller quantities of material, were used infrequently, or the total volume is unknown.

Table 2. Aquatic disposal sites formerly used in San Francisco Bay. After USCOE (1975b).

LOCATION	LAST DOCUMENTED YEAR OF USE	TYPE AND QUANTITY OF MATERIAL DISPOSED
Hunters Point	1966	Dredged sediment from nearby harbors (total volume unknown).
Yerba Buena Island	1970	Dredged sediment from the USCOE project at Oakland Harbor (27 million yd^3 from 1931 to 1970), U.S. Navy projects in Oakland Harbor (total volume unknown), and channels near Government Island (a total of 32,000 yd^3 in the 1950s and 1960s).
San Francisco Bay South	1975	Sediment excavated from Redwood City Harbor and various marinas in the lower South Bay (total volume unknown).
Concord Naval Weapons Station	1981	Unknown volumes of sediment dredged from the Naval Weapons Station were disposed of in nearby waters prior to the 1970s.
Alameda Naval Air Station	1975	Dredged sediment from the Alameda Naval Air Station was disposed of in nearby waters (12.3 million yd^3 were dredged from 1959 to 1975).
Angel Island East	1971	Dredged sediment from Richmond Harbor (12.3 million yd^3 from 1951 to 1971).
Morrow Island, Eastern Edge	1970	Sediment excavated from Suisun Slough was disposed of along the eastern edge of Morrow Island in 1970.
San Leandro Marina	mid-1960s	An unreported amount was dredged from San Leandro Marina.
Government Island	1940s	A Coast Guard facility disposed of unknown quantities of dredged sediment in the 1930s and 1940s.
Suisun Slough	1982	A total of 163,000 yd^3 dredged from Suisun Slough in 1960 and 1982 was disposed of southwest of the Suisun Slough Channel.

Fig. 12. Historic aquatic disposal sites in San Francisco Bay. After USCOE (1975b).

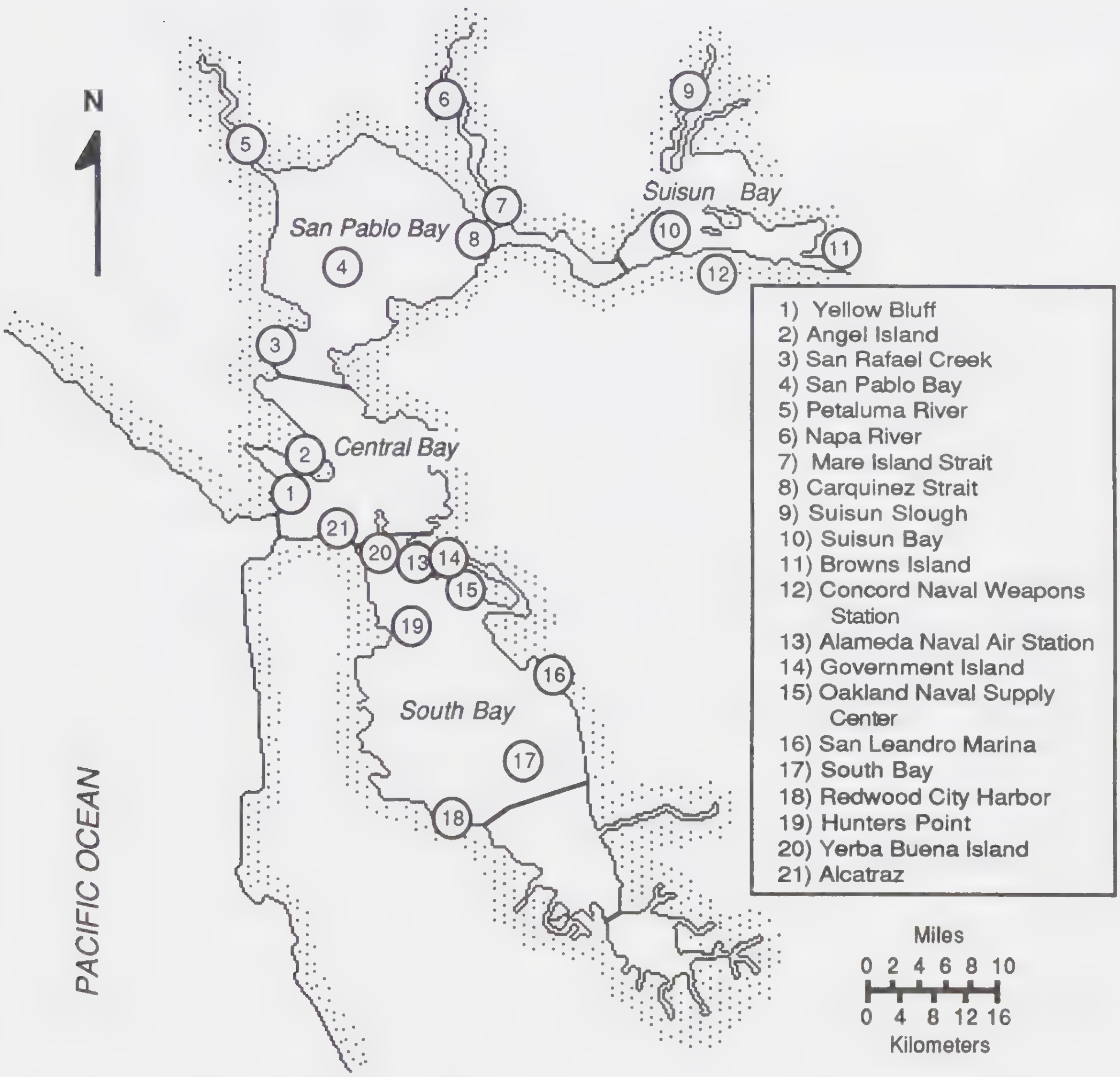


Table 3. Historic land disposal sites in San Francisco Bay. After USCOE (1975b).

LOCATION	LAST DOCUMENTED YEAR OF USE	TYPE AND QUANTITY OF MATERIAL DISPOSED
Browns Island	1975	An estimated 16,000 yd^3 dredged from New York Slough from 1965 to 1975
Suisun Slough	1982	In 1970, 91,000 yd^3 of dredged sediment was diposed of near Suisun Slough. Another 99,000 yd^3 was disposed of here in 1982.
Petaluma River	1983	Sediment excavated from the Petaluma River Channel (3.0 million yd^3 from 1941 to 1983).
Mare Island	Present	Land disposal at Mare Island of material dredged from Mare Island Strait began in the early 1970s and continues at present.
Napa River	1981	Dredged sediment from the Napa River Channel (a total of 1.2 million yd^3 were dredged on two occasions in 1962 and 1981).
Alameda Naval Air Station	1983	Dredged sediment from the Alameda Naval Air Station (a total of 33,000 yd^3 in 1981 and 1983), and sediment from the Oakland Naval Supply Center (total volume unknown).
Oakland Naval Supply Center	Early 1940s	Over 4 million yd^3 were dredged in the early 1940s and used as landfill at the Naval Supply Center.
Redwood City Harbor	1975	Dredged sediment from the Redwood City Harbor Project (total volume unknown), and other permitted projects in the vicinity (30,000 yd^3 between 1971 and 1975).
San Rafael Creek	1987	Sediment excavated from San Rafael Creek (1.6 million yd^3 from 1931 to 1987).
San Leandro Marina	1984	Dredged sediment from San Leandro Marina (5.1 million yd^3 from 1965 to 1984).
Concord Naval Weapons Station	1975	Sediment dredged at the Naval Weapons Station from 1943 to 1975 (total volume unknown).

D. OCEAN DISPOSAL SITES FOR DREDGED MATERIAL

Five ocean sites were employed for the disposal of dredged materials from the San Francisco Bay prior to 1986. These are described below.

The San Francisco Channel Bar (SF-8)

The San Francisco Channel Bar is a submerged sandbar about 5 km offshore, extending in an arc outside the Golden Gate. The site on the Bar that was designated by the USCOE to receive dredged sediment in 1972 (SF-8; Public Notice 72-61) is 305 m wide by 1,523 m long. Depths at this site range from 10.7 to 17.1 m, and average 12.2 m (USCOE, 1975b). Site designation for SF-8 allows for the disposal of sand with a grain size similar to that which occurs naturally at the site (USCOE, 1988b). This limits the disposal of sediment at this site to material derived from the San Francisco Main Ship Channel, also situated outside the Golden Gate.

A second disposal site in this vicinity, which has not been used since 1971, is a deepwater site outside the Golden Gate, about 1.6 km southwest of the Channel entrance. This site received all dredged material from the Main Ship Channel prior to 1971 (USCOE, 1975b). According to USCOE (1975b), about 27 million yd^3 (21 million m^3) was dredged from the Main Ship Channel and disposed at this site between 1931 and 1970.

Farallon Islands, 100-Fathom (182-m) Site

The 100-fathom disposal site close to the Farallon Islands lies approximately 53 km from the Golden Gate. The site is circular, with a radius of about 900 m. It was used for the disposal of dredged material from 1932 to 1980; disposal was prohibited in 1980 when the site was incorporated into the Gulf of the Farallones National Marine Sanctuary. The total amount of sediment disposed at the 100 fathom site has been estimated to be about 1 million yd^3 (760,000 m^3; USCOE, 1988b). The site was used infrequently due to its distance from dredging operations. The predominant use of the site was for disposal of highly contaminated sediments dredged from San Francisco Bay (USCOE, 1975b), including an unknown quantity of material dredged from the Oakland Harbor Project in the early 1970s (USCOE, 1975b).

In 1975, due to increasing EPA regulation, 172,000 yd^3 (132,000 m^3) of the more heavily contaminated material removed from the pier and approach area of the Alameda Naval Air Station by clamshell dredge was dumped at the 100-fathom site. A maximum of 250,000 yd^3 (191,000 m^3) of material from Alameda NAS was sufficiently contaminated to warrant disposal at either the 100-fathom site, or at Alcatraz (USCOE, 1975b). The final decision by the USCOE on the destination of the contaminated material was determined in coordination with the SFBRWQCB and the USEPA. For a time, the U.S. Navy investigated the feasibility of disposing dredged material on land at Skaggs Island, and an engineering feasibility study was prepared. This plan was never adopted (USCOE, 1975b).

Farallon Islands Test Site

The Farallon Islands test site lies about 62 km west of the Golden Gate, and 8.8 km west of the Farallon Islands. It is a rectangle 152 m wide by 305 m long. The site was used from 5 to 7 September, 1974, when approximately 4,000 yd^3 (3,060 m^3) of sediment was released by the USCOE as part of the Dredge Disposal Study. This controlled release was carried out in order to assess effects of the disposal of dredged material upon the substrate at the disposal site.

The BART Site

The BART dumpsite lies 1.8 km west of Seal Rock, at a depth of almost 22 m. This site received the bulk of the 5.7 million yd^3 (4.3 million m^3) of material excavated in the late 1960s during construction of the Trans-Bay Tube of the Bay Area Rapid Transit (BART) System (USCOE, 1988b).

E. OCEAN DISPOSAL SITES FOR MATERIALS OTHER THAN SEDIMENT

The ocean waters adjacent to the Golden Gate have been used in the past to dispose of materials other than dredged material, including refinery, acid, cannery, and radioactive wastes, as well as obsolete munitions (Table 4). Ocean disposal of these materials began in 1931. Due to direct regulation, financial considerations, or environmental concerns such disposal had ceased by the mid-1970s (IEC, 1973).

With the exception of material dredged from the Main Ship Channel by 1972 the disposal of material into the open ocean was limited to sediment that was considered to be too heavily contaminated to be disposed in the Bay (IEC, 1973). The following discussion reviews disposal of these materials, the types and quantities of materials disposed, disposal locations, and years during which the sites were used.

It is estimated that 1.2 billion liters (315 million gallons) of refinery wastes were disposed of in the open ocean between 1966 and 1972. Two of the known generators of this waste were Standard Oil (Richmond) and Shell Oil (Martinez). In the 1960s, Standard Oil discharged approximately 170 million liters (45 million gallons) of chemical wastes annually at a site stated to be at least 8 km offshore. After 22 December 1970, Standard Oil was required to dispose of such wastes at least 4.8 km beyond the Gulf of the Farallones. Shell Oil discharged its wastes at a location 80-160 km from shore. The composition of the waste, disposal frequency, and annual amount of discharge are unknown (IEC, 1973). Offshore disposal of these materials was prohibited after 31 December 1970.

Approximately 900 million liters (240 million gallons) of acid-iron wastes was disposed annually in the open ocean by the United States Steel Corporation. The disposal site was approximately 22 km southwest of the Golden Gate, 14.4 km offshore, in 36.5 m of water. Disposal of hydrochloric and sulfuric acid wastes began in 1948, and continued until April 1971 (IEC, 1973).

Table 4. Summary of wastes disposed of into ocean waters offshore of San Francisco, 1931-1972. After IEC (1973).

TYPE OF WASTE	PERIOD	QUANTITY DISPOSED
Refinery Wastes	1966-1972	1.2 billion L
Acid Wastes	1948-1971	900 million L yr^{-1}
Cannery Wastes	1960-1972	20,000 tonnes yr^{-1}
Radioactive Wastes	1946-1968	47,000 containers
Munitions	1968-1969	463 tonnes
Dredged Material	1935-1972	1 million yd^3

In 1960, six East Bay fruit and vegetable canneries contracted with the Oakland Scavenger Company to dispose of their wastes. The disposal site was about 26 km offshore from the Golden Gate, and 18 km southeast of the Farallon Islands, in approximately 79 m of water. This site received about 20,000 tons (18,000 tonnes) of cannery wastes annually, almost all of which was disposed between the months of July and October of each year. The disposed material consisted of the solid residues of the fruit and vegetable canning process. Open ocean disposal of cannery waste stopped by 1972 (IEC, 1973).

Between 1946 and 1968, an estimated 47,000 containers of radioactive wastes (Reish, 1978; NOAA, 1979; USCOE, 1988b) were disposed of at three sites, located approximately 3.5, 14, and 23 km from Southeast Farallon Island in the Gulf of the Farallones (NOAA, 1979). The amounts of radioactivity (as Curies) in these containers are unknown. The normal disposal container at that time was a 55-gallon (213-liter) drum, which held from a few grams to a few kilograms of waste (e.g., contaminated tools, gloves, protective clothing, transport containers, and other articles) encased in concrete (IEC, 1973). Thorium, uranium, transuranic elements, radionuclides produced by neutron activation and mixed fission products comprised the predominant waste elements (NOAA, 1979).

A site designated by the Navy for the disposal of obsolete munitions received approximately 463 tonnes (509 tons) of conventional munitions in 1968 and 1969. This disposal site (a trapezoid, with an approximate center at 37° 40' N and 123° 25' W) was located about 29 km west of the Farallon Islands, in more than 2,000 m of water. As part of a deepwater disposal plan known as Operation Chase, the *S.S. John F. Shafroth* (a derelict Liberty ship) was deliberately sunk on this site in 1964, with a cargo of approximately 236 tonnes (about 260 tons) of ammunition and explosives (IEC, 1973; MMS, 1987).

4. Summary of Historical Dredging and Disposal in the Estuary

Available data only allow assessment of historical trends relating to USCOE and U.S. Navy maintenance dredging between 1975 and 1985. Table 5 shows long-term, average rates of disposal for dredged material from maintenance projects at aquatic and upland sites (upland sites are usually low-lying areas around the margins of the Estuary). It was not possible to produce reliable overall estimates of amounts dredged in new work projects in the Estuary for this 11-yr period. Average dredging rates for all categories of projects, including new work and all work performed under permits issued by USCOE, are presented for the years 1986 and 1987 in Section V.A.

The average annual rate of dredged material disposal from maintenance projects in the San Francisco Bay region was 4.9 million yd^3 (3.7 million m^3) yr^{-1}. The two principal sites for disposal were at the Alcatraz and Carquinez Strait sites. The Alcatraz disposal site received an estimated average of 1.9 million yd^3 (1.5 million m^3) yr^{-1}, about 39% of the total volume dredged in the Estuary. The Carquinez Strait disposal site received 1.5 million yd^3 (about 1.1 million m^3) yr^{-1}, or 31% of the total volume dredged. Smaller amounts of material were disposed of on land (802,000 yd^3

Table 5. Average rates of disposal of material (millions $yd^3\ yr^{-1}$) from maintenance projects at aquatic and upland sites, 1975-1985. Data from USCOE (1989a) and U.S. Navy (1989).

Region	Type	Location	Annual Average Disposal 1975-1985
Bay[a]	Aquatic[b]	Alcatraz	1.896
		San Pablo	0.192
		Carquinez	1.513
	Upland		0.802
Delta	Upland		0.483
Total for the Estuary			**4.886**

[a]Total quantity disposed from the Bay to both aquatic and upland sites averaged 4.403 million $yd^3\ yr^{-1}$.

[b]Total in-Bay aquatic disposal volume averaged 3.601 million $yd^3\ yr^{-1}$.

[613,000m^3] yr^{-1}), at the San Pablo Bay disposal site (192,000 yd^3 [147,000 m^3] yr^{-1}), and a site in Suisun Bay (112,000 yd^3 [86,000 m^3] yr^{-1}). Maintenance of channels at Mare Island, Alameda Naval Air Station, Richmond Harbor, Oakland Harbor, and the Sacramento River and Stockton Deep Water Ship Channels accounted for most of maintenance dredging performed in the Estuary.

B. STUDIES OF THE EFFECTS OF DREDGING AND DISPOSAL IN THE ESTUARY

For many decades after dredging first took place in the Estuary, there was no recognition that such operations might have significant impacts on the environment. Disposal of dredged material occurred at numerous locations around the Estuary, typically near the sites of dredging, with dredged material dumped adjacent to the channel or disposed as upland fill. In response to growing national and local concerns over environmental degradation, this situation began to change in the late 1960s and early 1970s.

The USCOE began to incorporate environmental considerations into its permit review process in 1968 (USCOE, 1968). Environmental legislation (e.g., the *Clean Water Act*, Amendments of 1972; see Section III) assigned to the USCOE the responsibility of ensuring that all dredging projects in waters of the nation conformed to criteria that were established in order to prevent adverse effects of dredging and dredged material disposal on the environment. Along with these regulatory responsibilities, the USCOE was directed to conduct research to improve the technical basis for the management of dredged material, and to evaluate the environmental impact of dredging and disposal. The *River and Harbor Act* of 1970 authorized a 5-yr Dredged Material Research Program, which addressed all aspects of dredging activities, including dredging technology, loss of dredged material during dredging and disposal, effects of suspended particles on biota, contaminants in dredged material, and the availability of many different classes of pollutants to biota as the result of dredging and dredged material disposal (Saucier *et al.*, 1978). Additional programs (e.g., DOTS - the Dredging Operations Technical Support program) were developed within the USCOE at the Waterways Experiment Station, and continued to provide information on the environmental impacts of dredging and dredged material operations. In subsequent years, the Waterways Experiment Station has also managed several other major research programs on this subject (Engler *et al.*, 1988b).

Research on the effects of dredging and dredged material disposal in the San Francisco Estuary also commenced in the late 1960s. From 1967 to 1969, the U.S. Fish and Wildlife Service conducted field and laboratory studies to determine the ecological effects of dredging and disposal in San Francisco Bay (USCOE, 1977a). Additional research on the effects of dredged material disposal was conducted by the USCOE in 1970 and 1971 (USCOE, 1977a). In 1972, the San Francisco District initiated a detailed study (the Dredge Disposal Study) of the physical, chemical, and biological effects of dredging activities in the Bay. The Dredge Disposal Study consisted of many distinct lines of inquiry that were pursued over a 5-yr period (USCOE, 1977a). Table 6 lists the scope of the numerous components of the USCOE San Francisco District Dredge Disposal Study. While this study was in progress, the USCOE produced an EIS assessing the environmental effects of their maintenance

Table 6. General scopes of work of elements of the Dredge Disposal Study for the San Francisco Bay and Estuary. After USCOE (1977a).

Title	Scope	Reference
San Francisco Bar	Physical, chemical, and biological monitoring	USCOE, 1974
Pollutant Distribution	Sediment chemistry	USCOE, 1976a
Water Column	Effects on suspended solids and dissolved oxygen concentrations	USCOE, 1976b
Oxygen Sag	Effects on dissolved oxygen (DO) concentrations	USCOE, 1979b
Biological Community	Trends in abundance of benthic infauna	Liu *et al.*, 1975
Material Release	Fate of sediment tagged with an iridium tracer	USCOE, 1976c
Crystalline Matrix	Trace element release from dredged sediments	Serne and Mercer, 1975
Physical Impact	Effects of suspended solids, temperature, and DO on biota	Peddicord *et al.*, 1975
Pollutant Uptake	Trace element uptake during dredging	Anderlini *et al.*, 1975a
Pollutant Availability	Trace element and organochlorine release during disposal	Anderlini *et al.*, 1975b
Land Disposal	Feasibility of land disposal	IEC, 1974
Marsh Development	Laboratory and field studies of plant growth on dredged sediment	USCOE, 1976d
Ocean Disposal	Experimental release of material at an ocean site	USCOE, 1975a
Dredging Technology	Factors controlling dispersal patterns of dredged material	JBF Scientific Corporation, 1975

dredging projects, and Bay dredging activities in general (USCOE, 1975b). This EIS drew upon the findings of the partially completed Dredge Disposal Study.

The findings of both the Dredge Disposal Study (completed in 1977) and the Dredged Material Research Program were used by the San Francisco District of the USCOE to formulate a procedure for assessing the potential impacts of dredged material disposal in Bay waters (USCOE, 1978; Fong *et al.*, 1982). The central feature of this procedure was the use of the elutriate test (see Section V. E. of this report) to evaluate potential effects of remobilized contaminants on water quality. Prior to that, only bulk sediment analyses had been required (Fong *et al.*, 1982).

Concern over dredged material disposal in the Estuary increased in 1982, when it was discovered that dredged material released at the Alcatraz disposal site was failing to disperse as expected and was forming a mound at the site. By 1984, the peak of the mound had risen to -8.5 m (-28 ft) at MLLW (Trawle and Johnson, 1986) and posed a threat to navigation. Since the Alcatraz disposal site receives about 80% of the total volume of dredged sediment disposed of in Bay waters (see Section V. A. of this report), the discovery that its capacity to disperse material was being exceeded had significant ramifications for the management of dredged material throughout the Estuary.

In 1984, the USCOE San Francisco District initiated the Dredged Material Disposal Management Program (DMP) in response to the Alcatraz mounding problem. The DMP, which is still ongoing, is comprised of a host of studies addressing the following issues (Ogden Beeman & Associates, Inc., 1988a):

(i) The accumulation of dredged material at the Alcatraz site;
(ii) Bathymetric monitoring of the two disposal sites in San Pablo Bay and Carquinez Strait;
(iii) The availability and feasibility of potential alternate dredged material disposal options;
(iv) The fate of dredged material after open water disposal; and
(v) The designation of an open ocean disposal site.

Table 7 lists the studies completed, on-going, and planned under the DMP. Results of some of these studies are discussed in Section V.D.

Table 7. Research completed, ongoing, and planned under the USCOE San Francisco District Dredged Material Disposal Management Program (DMP).

Title	Scope	References
In-Bay Disposal Alternatives	Assess disposal alternatives, including aquatic and land sites	Nolte & Associates, 1986a,1986b, 1986c, 1986d
Land Disposal	Feasibility assessment based on existing information	Ogden Beeman & Associates Inc., 1988b
San Francisco Bay Marine Resources Survey	Potential effects of aquatic disposal on significant fisheries	WESCO, 1988 (draft)
Inventory of Maintenance Dredging Activities	Review historical records to determine annual shoaling rates	None as yet
Investigation of Structural Means to Reduce Dredging Needs	Feasibility assessment	Ogden Beeman & Associates Inc., 1988a
Fate of disposed sediment	Develop 2-dimensional model to assess fate of sediment released in open waters	Winzler and Kelly, Inc., 1985; Trawle, 1986; Trawle and Johnson, 1986; SAIC, 1987b; SAIC, 1987c; Teeter, 1987; USCOE, 1987a; Pankow, 1988
Contaminant Testing of the Alcatraz Mound	Further investigation of contamination demonstrated in the Oakland Harbor SEIS (USCOE, 1988)	None as yet
Ocean Disposal Site Designation Studies	Identify potential sites and conduct field studies for site designation purposes	Nybakken *et al.*, 1984; Kinnetic Labs, Inc., 1987; Tetra Tech Inc., 1987; Parr *et al.*, 1988a; Parr *et al.*, 1988b; Stevenson *et al.*, 1988a; Stevenson *et al.*, 1988b; USCOE, 1988b

V. CURRENT STATUS

A. DREDGING AND DISPOSAL IN THE ESTUARY: 1986 AND 1987

1. General

This Section presents estimates of the magnitude of dredging and disposal activities in the San Francisco Estuary in 1986 and 1987. Activities in the Bay are described separately from those in the Delta, reflecting distinct differences in dredged material management in the two regions. The San Francisco District of the USCOE regulates dredging and disposal in the Bay region, and the majority of sediment dredged from the Bay is discharged at three sites in relatively deep, open waters. The three sites have been chosen due to their dispersive nature; a dispersive site is located in a region of high current velocity and/or high turbulence, which result in the transport of disposed dredged material away from the site.

Disposal in the Delta is regulated by the Sacramento District of the USCOE. In the Delta dredged material is disposed in contained upland or shallow aquatic sites. Dredged material from the Sacramento District is also put to constructive use in the Delta, for example, in the creation of wetlands and the stabilization of levees.

USCOE San Francisco and Sacramento District records of dredging activities for 1986 and 1987 provide the basis for the following discussion (USCOE, 1989a; 1989b; 1989c). In 1986, the San Francisco District introduced a requirement that permittees perform bathymetric surveys before and after dredging. This resulted in improved estimates of the actual amounts of sediments dredged and the costs of dredging. Prior to 1986, pre- and post-dredge surveys were performed only on USCOE civil works dredging projects, where the surveys were (and still are) used to determine fees paid to dredging contractors. All the data presented below for the San Francisco District, therefore, are based on the more precise information collected since 1986. It should be noted that the data presented in this Section are compiled by calendar year, in contrast to the statistics presented in Section IV.A. of this report which were based on the USCOE fiscal year (Oct. 1 to Sept. 31).

In addition to the records of quantities dredged. the USCOE has, since the latter part of 1985, accumulated data on the frequency of dredged material disposal at the Alcatraz disposal site (USCOE, 1989d). The format and information content of record keeping for disposal event monitoring has been evolving; records available from 1986 and 1987 identify the disposal site, the vessel dumping (and/or vessel pushing), site of origin of the dredged material, the date of disposal, and the number of trips made each day by the vessel in question. These data are critical to an evaluation of the effect of disposal frequency on the potential for mounding at each disposal site, the size and magnitude of possible turbidity plumes arising from activity at disposal sites, sediment mass transport in the Estuary, and contaminant transport and distribution in the Estuary. These data on daily disposal events will be included in the evaluation of dredging activity at the Alcatraz site during 1986 and 1987.

2. Dredging and Disposal in the Bay

A. AQUATIC DISPOSAL

The Alcatraz Disposal Site (SF-11)

Sediment dredged from San Francisco Bay is released at three open water disposal sites (Fig. 13). Most of the dredged material disposed in San Francisco Bay in 1986 and 1987 (81%) was disposed at Alcatraz. Seventy percent of the dredging projects in the San Francisco District utilized the Alcatraz site.

Table 8 lists the projects disposing dredged material at Alcatraz in 1986 and 1987, the type of work, and volumes discharged each year. The Table is divided into dredging performed by the USCOE ("Civil Works" projects) and by other organizations. Data on Civil Works projects were obtained from the Construction Management Branch of the San Francisco District, and data on permit work were obtained from the Regulatory Branch of the San Francisco District.

Figure 14(a) shows a frequency distribution based upon the magnitude of the projects using the Alcatraz site in 1986 and 1987. Because of the recurring nature of dredging activities at some locations, a project is included in these counts for each calendar year in which disposal occurred. Over this period, 24% (11 of 46) of projects using the Alcatraz site disposed of small volumes of material (10,000 yd^3 [7,600 m^3] or less annually). Nine projects (20%) disposed of annual volumes of sediment ranging from 10,000 to 50,000 yd^3 (7,600 to 38,000 m^3). Twenty-three projects dredged and disposed material totalling less than 100,000 yd^3 (76,000 m^3) annually, and an equal number dredged and disposed of volumes exceeding 100,000 yd^3 (76,000 m^3) each year. Most of the projects of greater than 100,000 yd^3 (76,000 m^3) capacity fell into the 200,000-500,000 yd^3 category (153,000-382,000 m^3); 12 projects in this category accounted for 26% of the total number using Alcatraz.

A few projects accounted for the bulk of the material disposed of at Alcatraz. The largest volume released by a single project was an estimated 2.1 million yd^3 (1.6 million m^3) of new work dredging from the John F. Baldwin Ship Channel (at the Long Wharf in Richmond Outer Harbor) in 1986. This project alone contributed approximately 22% of the total released at Alcatraz in 1986 and 1987 (Fig. 14[b]). Three projects (Port of San Francisco, Richmond Outer Harbor, and Alameda Naval Air Station) accounted for another 21% of the total amount of sediment discharged. The Port of San Francisco generated 813,000 yd^3 (622,000 m^3) of new work dredging in 1987, Richmond Outer Harbor generated 632,000 yd^3 (483,000 m^3) of maintenance dredging in 1987, and the Alameda Naval Air Station generated 583,000 yd^3 (446,000 m^3) of dredged material from maintenance work in 1987. Thus, these four largest projects (in the two largest size classes) accounted for 43% of the total material disposed at Alcatraz.

Dredging type (i.e., new work or maintenance dredging), and the type of equipment used to remove the material (clamshell, hopper, or hydraulic dredge)

Fig. 13. Aquatic disposal sites presently used in the San Francisco Estuary.

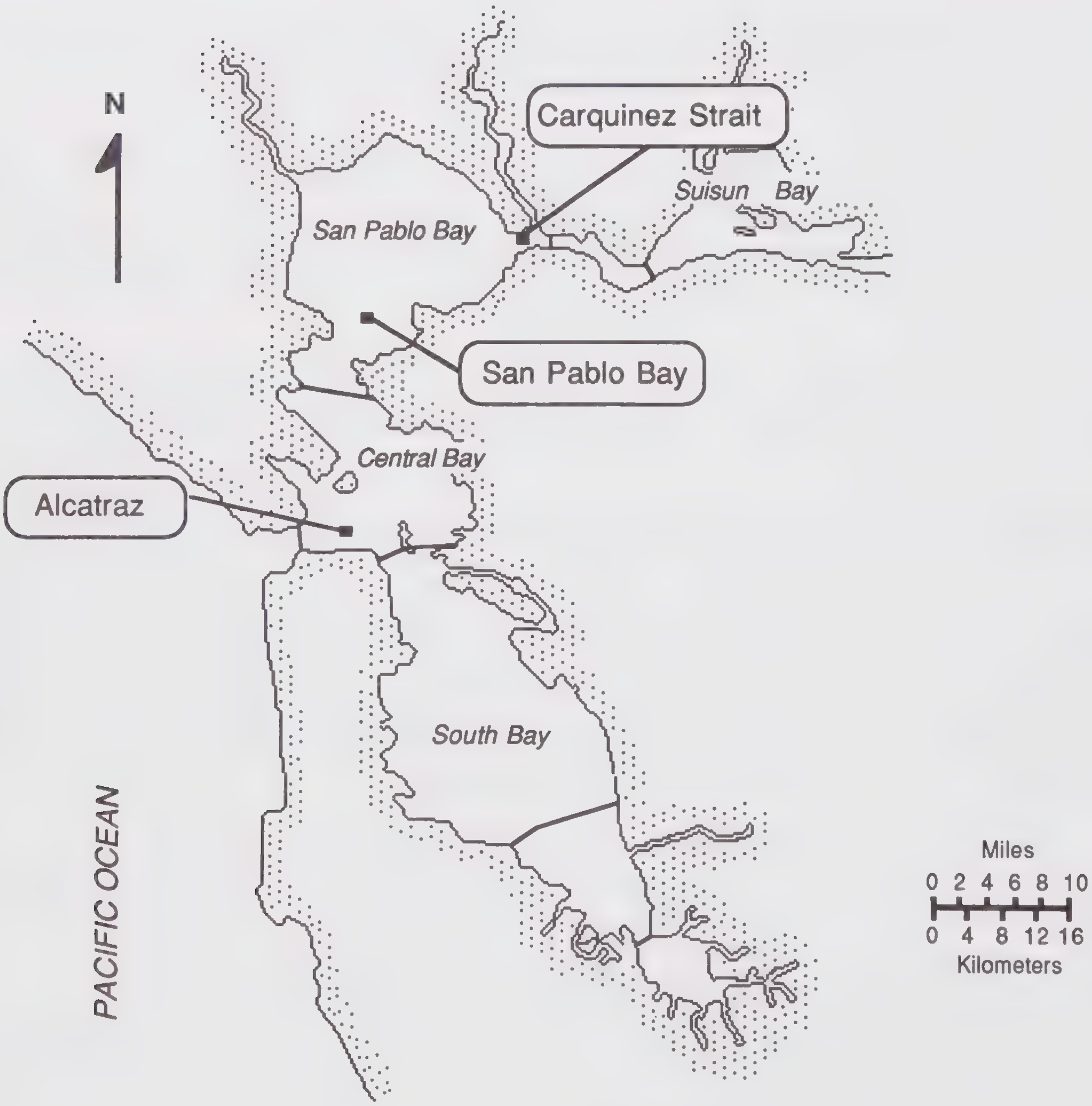


Table 8. Civil Works and Permitted projects disposing of dredged sediment at the Alcatraz site in 1986 and 1987, the type of work, and volumes discharged (yd^3) each year. Data from USCOE (1989a, 1989b) and U.S. Navy (1989). Project types as follows: M, maintenance; N, new work. Dredge types as follows: H, hopper; C, clamshell; P, pipeline.

CIVIL WORKS PROJECTS				
Project Name	**Project**	**Type**	**1986**	**1987**
Oakland Inner Harbor	M	H	0.218	0.393
Oakland Outer Harbor	M	H	0.261	0.476
Richmond Inner Harbor	M	H	0.426	0.432
Richmond Outer Harbor	M	H		0.632
Richmond Outer Harbor (John F. Baldwin)[a]	N	H,C	2.075	
San Rafael Creek	M	C	0.198	
Corte Madera	M	P	0.094	0.176
Subtotal for Civil Works			*3.272*	*2.109*

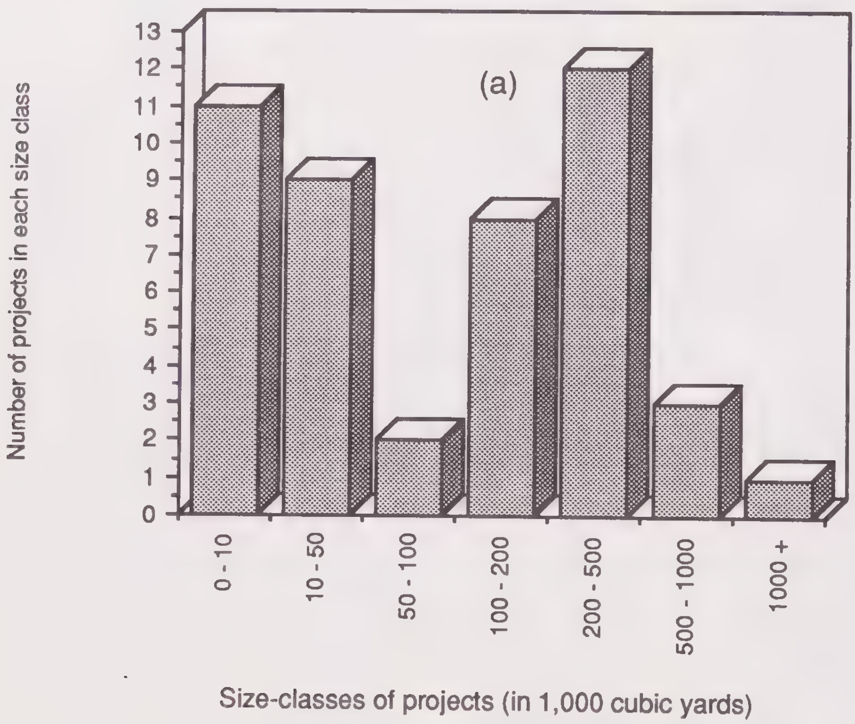
PERMITTED PROJECTS				
Project Name	**Project**	**Type**	**1986**	**1987**
S.F. Redevelopment	N	C	0.042	
Port of San Francisco	M	C	0.316	0.162
Schnitzer Steel	M	C	0.004	0.020
Triple A Machine Shop	M	C	0.102	
Triple A Machine Shop[b]	M	C	0.088	
Port of Oakland	M	C	0.013	0.033
Chevron USA	M	C	0.248	0.066
Harbor Bay Business Park	M	C	0.006	
USCG 12th District	M	C	0.009	0.037
Clipper Yacht Harbor	M	C	0.007	
City of Oakland	M	C	0.209	
Richmond Yacht Harbor	M	P	0.026	
Schoonmaker Marina	N	C	0.103	
Sausalito Yacht Harbor	M	C	0.002	0.001
Coyote Point Marina	M	C	0.042	0.036
US Navy, Alameda NAS	M	H	0.247	0.583
US Navy, Point Molate	M	C		0.118
Port of San Francisco[b]	N	H		0.813
Brickyard Cove	M	C		0.192
US Navy, Oakland NSC	M	H		0.239
Port of Oakland[b]	N	C		0.005
Chevron Outfall	N	C		0.268
Paradise Cay	M	C		0.024
USCG 12th District[b]	N	C		0.004
Encinal Marina	M	C		0.004
Presidio Yacht Club	M	C		0.001
Texaco	M	H		0.005
Subtotal for Permit Work			*1.464*	*2.611*

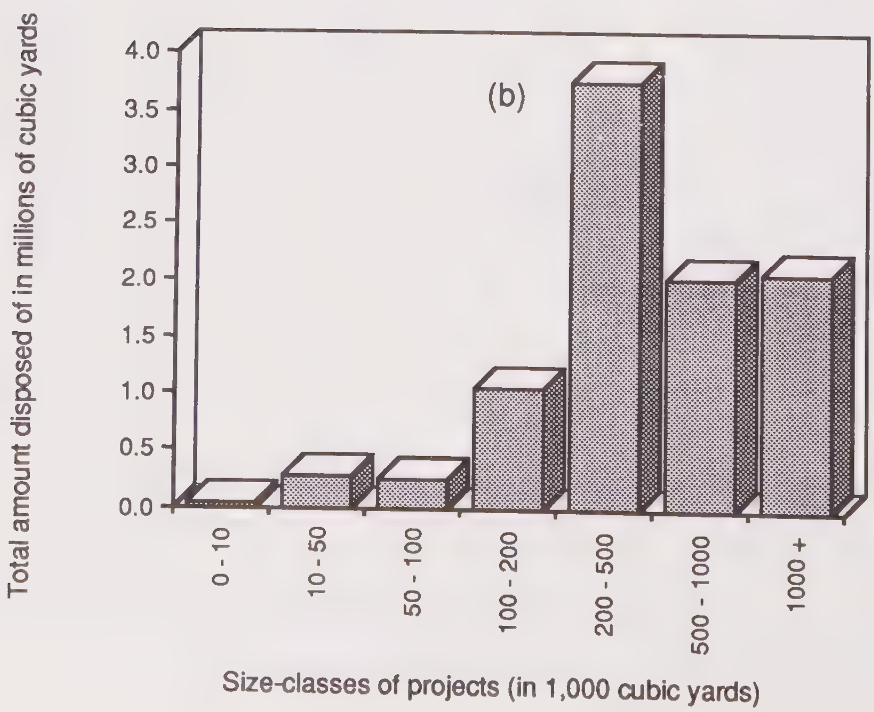
TOTAL FOR ALCATRAZ			*4.736*	*4.720*

[a] Includes an estimated 1.624 million yd^3 dredged in January through April and 0.451 million yd^3 dredged in October and November.

[b] Dredging performed under a different permit than previous entry with the same name.

Fig. 14. Distribution of projects using the Alcatraz site in 1986 and 1987: (a) among various size-classes (in 1,000 yd^3) of amounts disposed, and (b) total volumes disposed of by each size-class. Because of the recurring nature of dredging activities at some locations, a project is included in these counts for each calendar year in which disposal occurred. Data from USCOE (1989a; 1989b).





influences the fate of disposed material (see Section V.C. for detailed discussion). Seven new work projects disposed 35% of the total material transported to Alcatraz in 1986 and 1987 (Table 8). The remaining 65% of the material disposed at the Alcatraz site during this time was from maintenance projects. New work dredging was performed using both hopper dredges and clamshell dredges. It is not possible to estimate amounts of new work dredging performed using these two types of dredges because the John F. Baldwin Channel, which contributed 63% of the new work material, used both hopper and clamshell dredges, and the amounts collected by each are unknown (see Table 8). Another major new work project employing a hopper dredge was the Port of San Francisco (813,000 yd^3 [622,000 m^3] in 1987). New work projects using clamshell dredges included the John F. Baldwin Ship Channel (quantity unknown), the Chevron Outfall (268,000 yd^3 [205,000 m^3] in 1987), and the Schoonmaker Marina (103,000 yd^3 [79,000 m^3] in 1986).

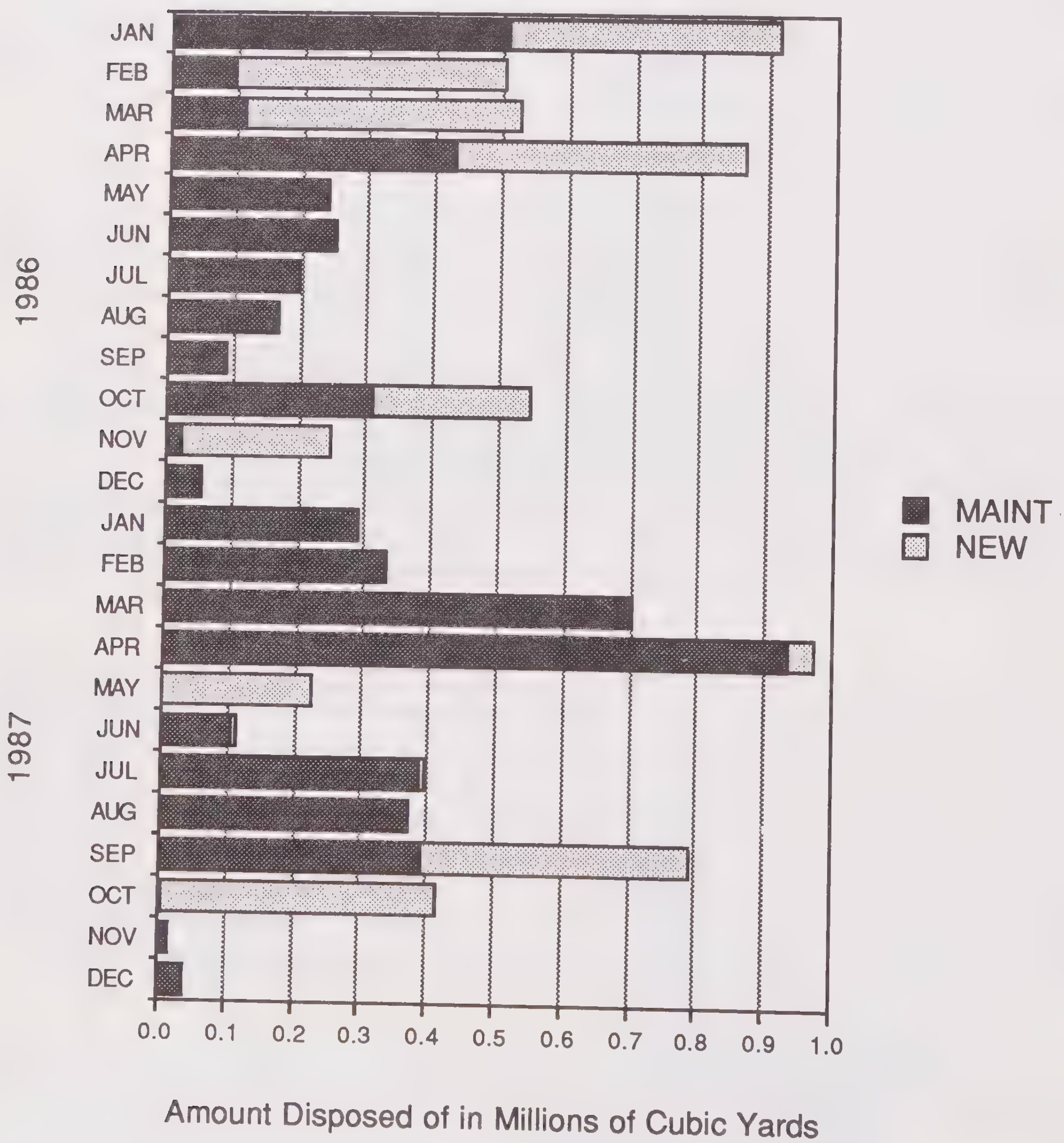
Dredged material from 19 maintenance projects was disposed at Alcatraz in 1986, and 20 maintenance dredging projects employed the site in 1987. Material from these projects was collected using hopper dredges (63% of total volume), clamshell dredges (31%), and hydraulic dredges (6%; Table 8).

Monthly disposal rates at Alcatraz were influenced strongly by a few large projects. Figure 15 shows approximate disposal quantities for each month during 1986 and 1987. Monthly disposal data were available for permit work, but not for USCOE civil works projects. Monthly disposal volumes for civil works projects were consequently estimated by distributing equal fractions of the total volume dredged for each project over the months in which the project was active. Figure 15 is therefore only a low-resolution representation of the timing and magnitude of projects in 1986 and 1987.

Obvious peaks of disposal activity are evident in Fig. 15. Each peak is largely attributable to either one or two of the major dredging projects. The large amounts of material disposed in January-April 1986 were primarily the result of new work in the John F. Baldwin Ship Channel (approximately 1.6 million yd^3 [1.2 million m^3]). Other major civil works projects contributing to the disposal activity in early 1986 included the Richmond Inner Harbor (213,000 yd^3 [163,000 m^3] in January) and the Alameda Naval Air Station (247,000 yd^3 [189,000 m^3] from January to March). After a hiatus in dredging activity from May to September 1986, work on the John F. Baldwin project generated an additional 450,000 yd^3 (344,000 m^3) of material in October and November 1986.

The largest single pulse of dredged material disposed during the 2-year period occurred in April 1987, when projects at the Alameda Naval Air Station (583,000 yd^3 [446,000 m^3] in April) and civil works dredging of Oakland Inner Harbor (393,000 yd^3 [300,000 m^3] in February-April) and Oakland Outer Harbor (476,000 yd^3 [364,000 m^3] in February-April) were active simultaneously. Maintenance work in Richmond Inner Harbor (432,000 yd^3 [330,000 m^3]) and Richmond Outer Harbor (632,000 yd^3 [483,000 m^3]) in July-September 1987 added significantly to the total volume disposed in those months. The Port of San Francisco also disposed of substantial quantities of

Fig. 15. Monthly trends in disposal at the Alcatraz disposal site in 1986 and 1987. Dark portions of bars represent quantities derived from maintenance projects; light portions of bars represent quantities derived from new work projects. Data from USCOE (1989a; 1989b).



new work material in September (400,000 yd^3 [306,000 m^3]) and October (413,000 yd^3 [316,000 m^3]) of 1987.

As described above, the San Francisco District of USCOE (1989d) has also monitored the number of dumps made each day by disposal barges. Data are available for the period January 1986 through December 1987; however, data for April and May 1987 are missing from the record. Figure 16 shows the frequency distribution of counts of dumps per day for the 2-year period. Disposal did not take place on 23.7% of the days. On most days, however, disposal did occur. Ten or more dumps were made on 32.5% of the days during this period. Twenty or more dumps were made 10.1% of the time. Although it was not common for 30 or more dumps to occur on a single day, a maximum of 41 was recorded on 31 January 1986. No data are available for 7.1% of the days during this period, as mentioned above.

Active dredging of major projects, such as those discussed above (Richmond Harbor, Oakland Harbor, and Alameda Naval Air Station), accounted for most of the days with high frequencies of dumping at Alcatraz. Consequently, days with heightened disposal activity often occurred in succession. Average numbers of dumps per day for each month are shown in Fig. 17. As might be expected, the pattern apparent in this graph is quite similar to that in Fig. 15. A maximum of 26 dumps per day was observed in February 1986 (717 total for the month). Other months with relatively high averages were March 1986 (21 trips per day, 647 for the month) and September 1987 (20 trips per day, 604 for the month). The standard deviations calculated for February 1986, March 1986, and September 1987 (Fig. 17) were similar to those for other months, indicating that frequencies of disposal were consistently high in those months. In February 1986, for example, greater than 20 dumps occurred on 26 of 28 days. It is unfortunate that data are not available for April 1987, as the estimated quantity dredged during this month (Fig. 15) suggests that the frequency of disposal must have been comparable to the other months with maximum activity.

The implications of these periods of high-frequency disposal are many. For example, frequent dumping may well have significant effects upon key environmental parameters, including consolidation of disposed dredged material, turbidity plumes arising from the disposal process, release of sediment-sorbed contaminants to the water column, bioavailability of contaminants in sediments, and transport of contaminants from dredged material disposal sites to other portions of the Estuary. These topics will be discussed in detail in Sections V.C. and V.D. of this report.

The San Pablo Bay Disposal Site (SF-10)

Dredged material from four projects was disposed at the San Pablo site in 1986. Material from six projects was disposed at SF-10 in 1987 (Table 9). Two civil works projects at the Petaluma River (266,000 yd^3 [203,000 m^3]) and Pinole Shoal (309,000 yd^3 [236,000 m^3]) contributed 91% of the total dredged material disposed at the San Pablo site in the 2-year period. All of the other dredging projects that disposed at the San Pablo site contributed fewer than 20,000 yd^3 (15,000 m^3). All of the dredged material discharged at the San Pablo Bay site came from maintenance dredging of existing channels. With the exception of the Pinole Shoal project, which

Fig. 16. Frequency distribution of counts of dumps per day at the Alcatraz disposal site, January 1986 to December 1987. Data from USCOE (1989d).

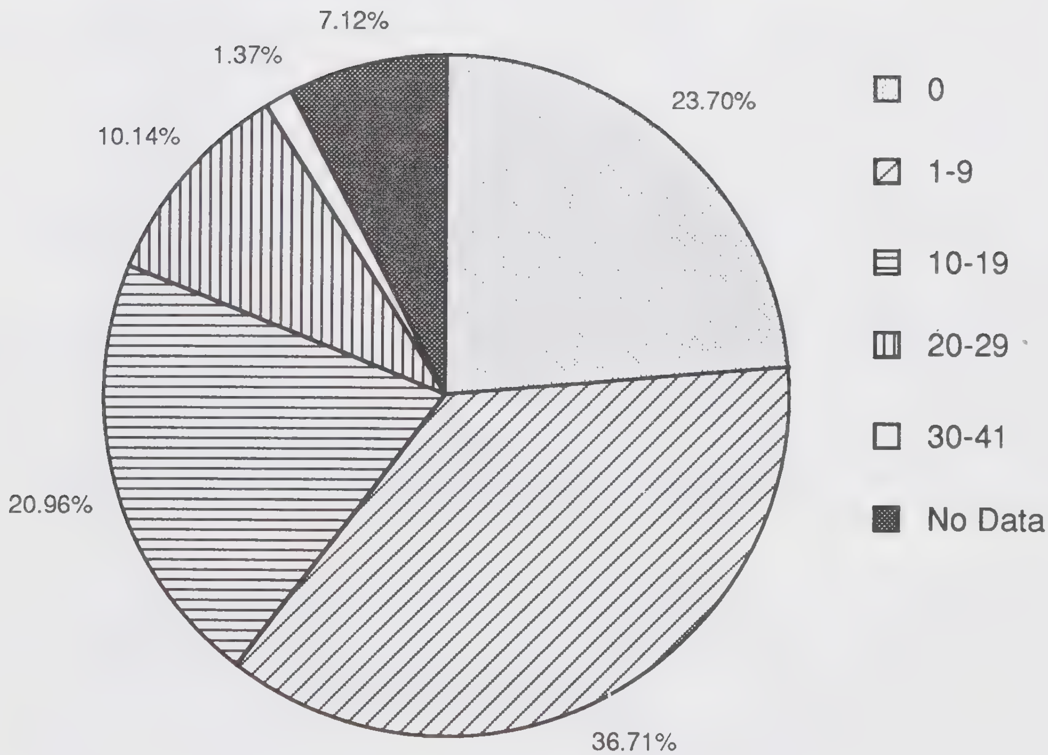


Fig. 17. Average numbers of dumps per day occurring each month at the Alcatraz disposal site, January 1986 to December 1987. Data from USCOE (1989d).

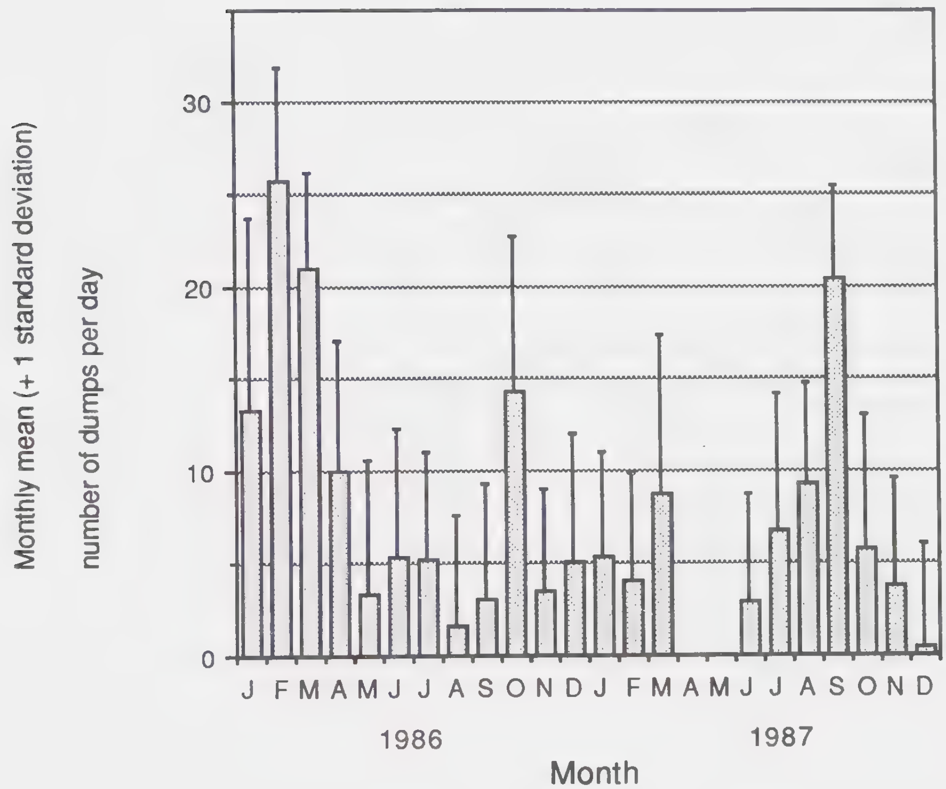


Table 9. Civil Works and Permitted projects disposing of dredged sediment at the San Pablo Bay disposal site in 1986 and 1987, the type of work, and volumes discharged each year. Data on Civil Works projects were obtained from the Construction Management Branch of the San Francisco District (USCOE, 1989a), and data on permit work were obtained from the Regulatory Branch of the San Francisco District (USCOE, 1989b). Project types as follows: M, maintenance; N, new work. Dredge types as follows: H, hopper; C, clamshell; P, pipeline.

CIVIL WORKS PROJECTS				
Project Name	**Project Type**		**1986**	**1987**
Petaluma River	M	C	0	0.266
Pinole Shoal	M	H	0	0.309

PERMITTED PROJECTS				
Project Name	**Project Type**		**1986**	**1987**
San Rafael Rock Quarry	M	C	0.017	0.009
City of Petaluma	M	C	0.010	
Unocal	M	C	0.003	
Marina Vista	M	C	0.003	
Loch Lomond Marina	M	C	0.001	
Greenbrae Marina	M	C	0.009	
Unocal[a]	M	C	0.005	

TOTALS FOR SAN PABLO	*0.048*	*0.584*

[a] Dredging performed under a different permit than previous entry with the same name.

employed a hopper dredge, all the dredged material disposed at the San Pablo site came from clamshell dredges.

The temporal pattern of disposal at the San Pablo site (Fig. 18) shows that 70% of the total dredged material disposed in 1986 and 1987 was discharged in a period of two months (October-November, 1987). This material came from the Petaluma River and Pinole Shoal projects. Figure 18 also shows that in 13 of 24 months no disposal took place at the San Pablo Bay site.

The Carquinez Strait Disposal Site (SF-9)

Dredged material from four projects was disposed at the Carquinez Strait disposal site (SF-9) in 1986. Material from six projects was disposed there in 1987 (Table 10). Maintenance dredging of the Mare Island Strait produced the majority of the material released at Carquinez in these 2 years (808,000 yd^3 [618,000 m^3] in 1986 and 449,000 yd^3 [343,000 m^3] in 1987). These volumes comprised 77% of the 2-year total for the site. Annual totals of dredged material from all other projects were less than 90,000 yd^3 (69,000 m^3). As at the San Pablo Bay disposal site, all of the projects disposing at the Carquinez Strait site were maintenance projects. Hopper dredges were used to collect 86% of the total volume disposed (including all the material from Mare Island Strait); the remaining 14% was collected using clamshell dredges. The temporal pattern of quantities discharged (Fig. 19) is dominated by material from dredging Mare Island Strait in May-July 1986 and February-March 1987. Quantities disposed in other months were all less than 95,000 yd^3 (73,000 m^3). In 11 of 24 months, no disposal took place at the Carquinez Strait site.

B. LAND DISPOSAL

A portion of the sediment dredged from San Francisco Bay is disposed of at contained, upland sites. Maintenance dredging of the Mare Island Strait produces the largest quantities of sediment disposed of on land. The Navy disposed of 452,000 yd^3 (346,000 m^3) in 1986 and 441,000 yd^3 (337,000 m^3) in 1987 at upland sites on Mare Island (Table 11; U.S. Navy, 1989).

According to USCOE estimates, dredged material amounting to 221,500 yd^3 (169,000 m^3) from 12 other, smaller projects was disposed at upland sites in 1986 (Table 11). The total volume dredged in each of these projects was less than 50,000 yd^3 (38,000 m^3; USCOE, 1989b). The USCOE further estimates that 16 other projects disposed of 511,000 yd^3 (391,000 m^3) to upland sites in 1987 (Table 11). With the exception of one project (Tutor-Salba-Perini; 180,000 yd^3 [138,000 m^3]), each of these projects required the disposal of less than 55,000 yd^3 (42,000 m^3; USCOE, 1989b).

3. Dredging and Disposal in the Delta

Smaller quantities of sediment are dredged from the Delta than are dredged from San Francisco Bay. USCOE civil works projects generate the bulk of the dredged material from the Delta region. In 1986 and 1987, maintenance dredging on two such

Fig. 18. Monthly trends in disposal at the San Pablo Bay disposal site in 1986 and 1987. All dredged material disposed of at this site was derived from maintenance projects. Data from USCOE (1989a; 1989b).

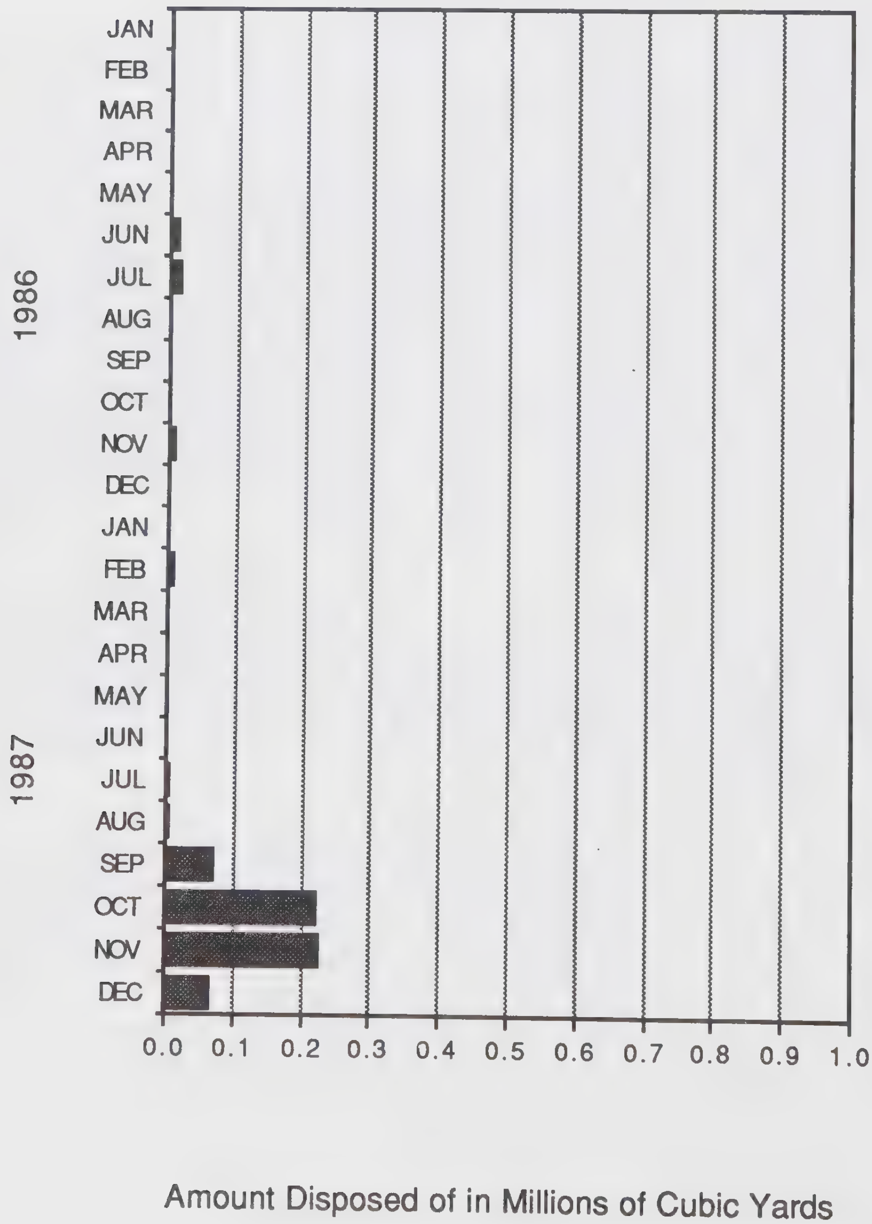


Table 10. Civil Works and Permitted projects disposing of dredged sediment at the Carquinez Strait disposal site in 1986 and 1987, the type of work, and volumes discharged each year. Data on Civil Works projects were obtained from the Construction Management Branch of the San Francisco District (USCOE, 1989a), and data on permit work were obtained from the Regulatory Branch of the San Francisco District (USCOE, 1989b). Project types as follows: M, maintenance; N, new work. Dredge types as follows: H, hopper; C, clamshell; P, pipeline.

CIVIL WORKS PROJECTS				
Project Name	**Project Type**		**1986**	**1987**
Mare Island Strait	M	H	0.808	0.449
Suisun Bay Channel	M	H		0.047
PERMITTED PROJECTS				
Project Name	**Project Type**		**1986**	**1987**
Maritime Administration	M	H	0.090	
Benicia Port Terminal	M	C	0.053	0.035
Exxon	M	C	0.042	0.040
Contra Costa Water District	M	C		0.008
Vallejo Ferry Terminal	M	C		0.055
TOTALS FOR CARQUINEZ			*0.993*	*0.634*

Fig. 19. Monthly trends in disposal at the Carquinez Strait disposal site in 1986 and 1987. All dredged material disposed of at this site was derived from maintenance projects. Data from USCOE (1989a; 1989b).

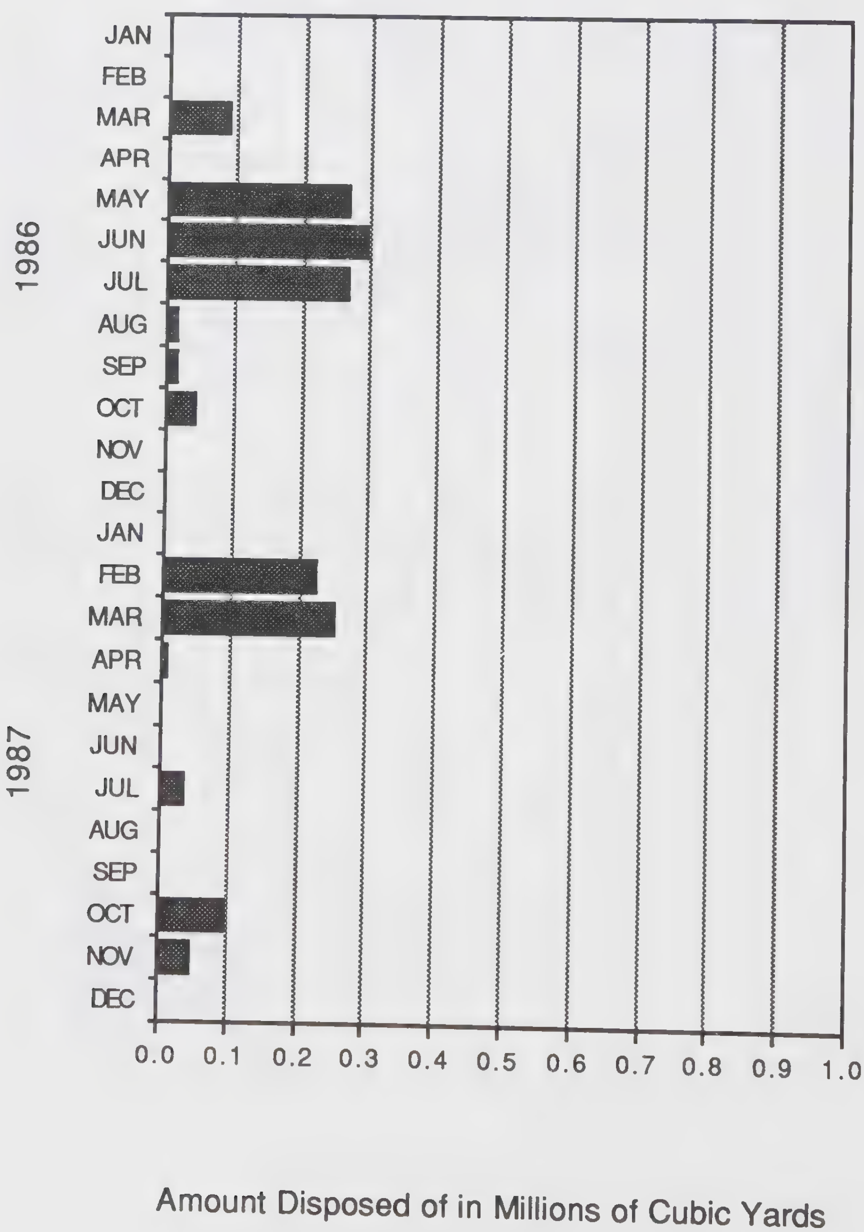


Table 11. Civil Works and Permitted projects disposing of dredged material from the Bay at upland sites. Note that data are compiled by USCOE fiscal year (1 October - 30 September), and are estimates listed in permits, unlike other data discussed in this Section. Data from USCOE (1989a).

CIVIL WORKS PROJECTS		
Project Name	**1986**	**1987**
San Rafael Creek		54,275

PERMITTED PROJECTS		
Project Name	**1986**	**1987**
Mare Island Naval Shipyard	452,000	441,000
City of Vallejo	20,000	20,000
Marin Co. Flood Control	13,500	13,500
Union Oil	3,750	3,750
Albert Giovanni	2,000	2,000
City of Martinez	50,000	50,000
Western Waterways	5,000	5,000
City of San Leandro	42,500	42,500
Town of Tiburon	7,500	7,500
City of Pittsburg	3,750	3,750
Ernest Hahn, Inc.	3,500	3,500
Granite Construction Co.	50,000	48,000
Leslie Salt Co.	20,000	20,000
Alameda Co. Flood Control		50,000
Contra Costa Co. Water District		3,000
Tutor-Salba-Perini		180,000
C.J. Development Co.		5,000

TOTAL LAND DISPOSAL	*673,500*	*952,775*

civil works projects (the Sacramento River and Stockton Deep Water Ship Channels) was in progress.

Maintenance dredging of the Sacramento River Deep Water Ship Channel produced 941,000 yd^3 (719,000 m^3) of sediment in 1986 (USCOE, 1989c). The sediment was dredged using a cutter head hydraulic dredge and was disposed at several upland sites along the River. No dredging was performed for this project in 1987. Maintenance dredging of the Stockton Deep Water Ship Channel in 1987 removed 285,000 yd^3 (218,000 m^3; USCOE, 1989c). This material was collected using hydraulic and clamshell dredges and was disposed on land. Dredging did not take place in 1986 for this project.

The volumes of sediment dredged and disposed by other projects in the Delta, including those operating under standard permits and regional permits, were not measured. This was either because volume estimates are not required under standing permits, or because the requirement to provide volume estimates was not enforced. Approximately 10 or fewer standard permits are active each year in the Delta, and their proportion of the annual totals for the Delta are inconsequential (A. Champ, USCOE, communication).

One important regional permit issued by the Sacramento District (in USCOE Public Notice GP-014) authorizes Reclamation Districts, governments, and property owners to dredge for the repair and maintenance of levees in the Delta. If it could be estimated, the amounts of material dredged under the authority of this permit might be significant. However, the Sacramento District Office of the USCOE did not collect sufficient information to allow such an estimate to be made.

4. Summary of Dredging and Disposal in the Estuary

A total of about 7.4 million yd^3 (5.7 million m^3) of material was dredged in the Estuary during 1986. In comparison to other estuaries, this is approximately equivalent to the average amount of material dredged from New York Harbor each year (8.8 million yd^3 [6.7 million m^3] yr^{-1}; New York District, USCOE, 1988e); considerably more than the amount dredged in Puget Sound (about 1.5 million yd^3 [1.1 million m^3] yr^{-1}; USCOE, 1988f); and substantially less than the amount dredged annually in maintenance of channels in the Rhine River Estuary at Rotterdam, Holland (30 million yd^3 [23 million m^3] yr^{-1}; Nijssen, 1988). Seventy-eight percent of the total volume (about 5.8 million yd^3 [4.4 million m^3]) was disposed at aquatic sites. For 1987 the corresponding values were about 7.2 million yd^3 (5.5 million m^3) total dredged material, with 83% of the total volume (about 6 million yd^3 [4.6 million m^3]) disposed at aquatic sites. Table 12 presents the distribution of annual average volumes among various categories of disposal employed in the 2-year period. Figure 20 shows the percentage of the total amount of dredged sediment attributed to each category.

The Alcatraz disposal site was employed for 65% of the total amount of dredged sediment, an annual average of about 4.7 million yd^3 (3.6 million m^3) yr^{-1}. Other disposal sites received smaller quantities of material, ranging from 316,000 to 813,000 yd^3 (242,000 to 622,000 m^3), or 4 to 11% of the total amount dredged. A total of about

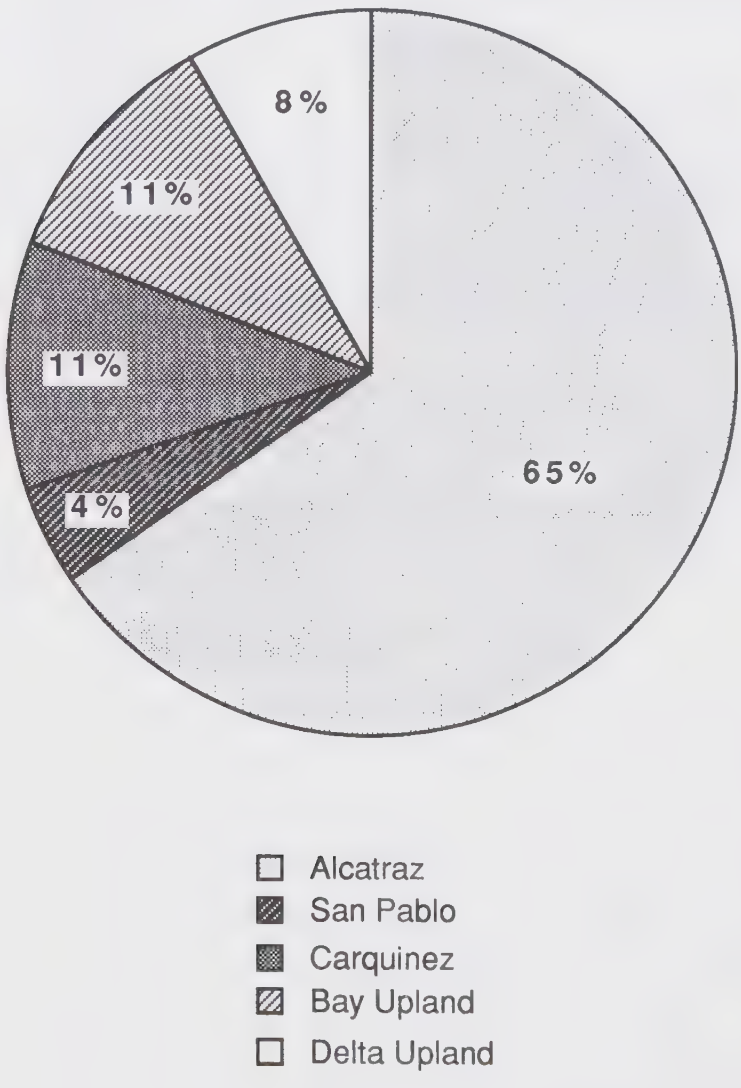
Table 12. Average rates of dredged material disposal at various locations in the San Francisco Estuary during 1986 and 1987. Data are presented as annual averages over the 2-year period, in million $yd^3\ yr^{-1}$. Sources of the data are described in the text.

Region	Type	Location	Average Disposal in 1986 and 1987
Bay[a]	Aquatic[b]	Alcatraz	4.728
		San Pablo	0.316
		Carquinez	0.813
	Upland		0.812
Delta	Upland		0.613
Total for the Estuary			**7.282**

[a] Total quantity disposed from the Bay to both aquatic and upland sites averaged 6.669 million $yd^3\ yr^{-1}$.

[b] Total in-Bay aquatic disposal volume averaged 5.857 million $yd^3\ yr^{-1}$.

Fig.20. Average amounts of dredged material disposed of at various locations in the San Francisco Estuary during 1986 and 1987. Data are expressed as percent of total disposal.



5.9 million yd^3 (4.5 million m^3) was disposed annually at aquatic disposal sites in the Bay. An average of about 1.4 million yd^3 (about 1.1 million m^3), or 20% of the total annual amount dredged for the Estuary, was disposed at upland disposal sites in the Bay and Delta regions.

B. CHARACTERISTICS OF DREDGED MATERIAL

Knowledge of the characteristics of sediments dredged and disposed is critical in any assessment of the effects of dredging on the San Francisco Estuary. Physical characteristics of the sediments (e.g., grain-size distribution, consolidation, mineral content, water content, specific gravity) will affect their behavior at each step in the process: dredging, barge or hopper filling, disposal and, ultimately, dispersion of the material from the disposal site. Chemical characteristics of the sediments (e.g. organic carbon content, pH, Eh, concentrations of associated contaminants) will affect the extent to which sediments may act as "sinks" for contaminants, and whether the sediments may act as sources of contamination to the water column, or to biota, after disposal. This section addresses the characteristics of sediments in the San Francisco Estuary with regard to the distribution of sediment types and the abundance of chemical contaminants in sediments from various portions of the the Estuary. The physico-chemical nature of contaminated sediments and the potential impact of these contaminants upon estuarine biota is considered in Section V.D.

1. Distribution of Sediment Types in the Estuary

With the exception of portions of Central Bay nearest the Golden Gate, the San Francisco Estuary is very shallow, with wide intertidal and subtidal regions cut by narrow, mid-Bay channels (Nichols and Thompson, 1985b; Fig. 21). Greater than 40% of the Estuary is less than 2 m deep, and over 70% is less than 5 m deep (Nichols *et al.*, 1986; Wright and Phillips, 1988). The sediments of San Francisco Bay change on a time scale of days to months. The dynamic nature of the sediment compartment of the Estuary was demonstrated by the sediment survey of SAIC (1987a). Most of the sites studied by these investigators showed evidence of recent sediment erosion, redistribution or deposition. On a short-term basis, Nichols and Thompson (1985b) noted that sand waves standing from 20 cm to 8 m in height move with the ebb and flow of tide, resulting in a continual sediment turnover to a depth of about 40 cm every few days. On a time scale of weeks, the intertidal mud-flat environment of the Estuary may show rapid changes in elevation (Luoma and Bryan, 1978; Nichols and Thompson, 1985b), as well as changes in sediment grain size.

Sediments in the Estuary fall into three categories: sandy bottoms in the channels; shell debris over a wide expanse of the South Bay (derived from the remnants of oyster beds [Wright and Phillips, 1988]); and soft deposits (known as "Bay Mud") underlying the vast expanses of shallow water (Fig. 22). Regions of the Estuary where currents are strong, including the deep channels of the Bay and the central channels of the major rivers in the Delta, generally have coarser sediments (i.e., fine sand, sand, or gravel). Areas where current velocities are lower, such as the shallow fringes of each sub-embayment of San Francisco Bay (see Fig. 22), are covered with Bay Mud (USCOE, 1976a). Bay Mud is comprised of silt and clay particles deposited as a result of flocculation, or "salting out," a process in which particulate matter in freshwater aggregates when mixed with more saline waters. The settling velocity of the aggregates is much greater than that of the original clay and silt particles, increasing particle deposition.

Fig. 21. Bathymetry of San Francisco Bay.

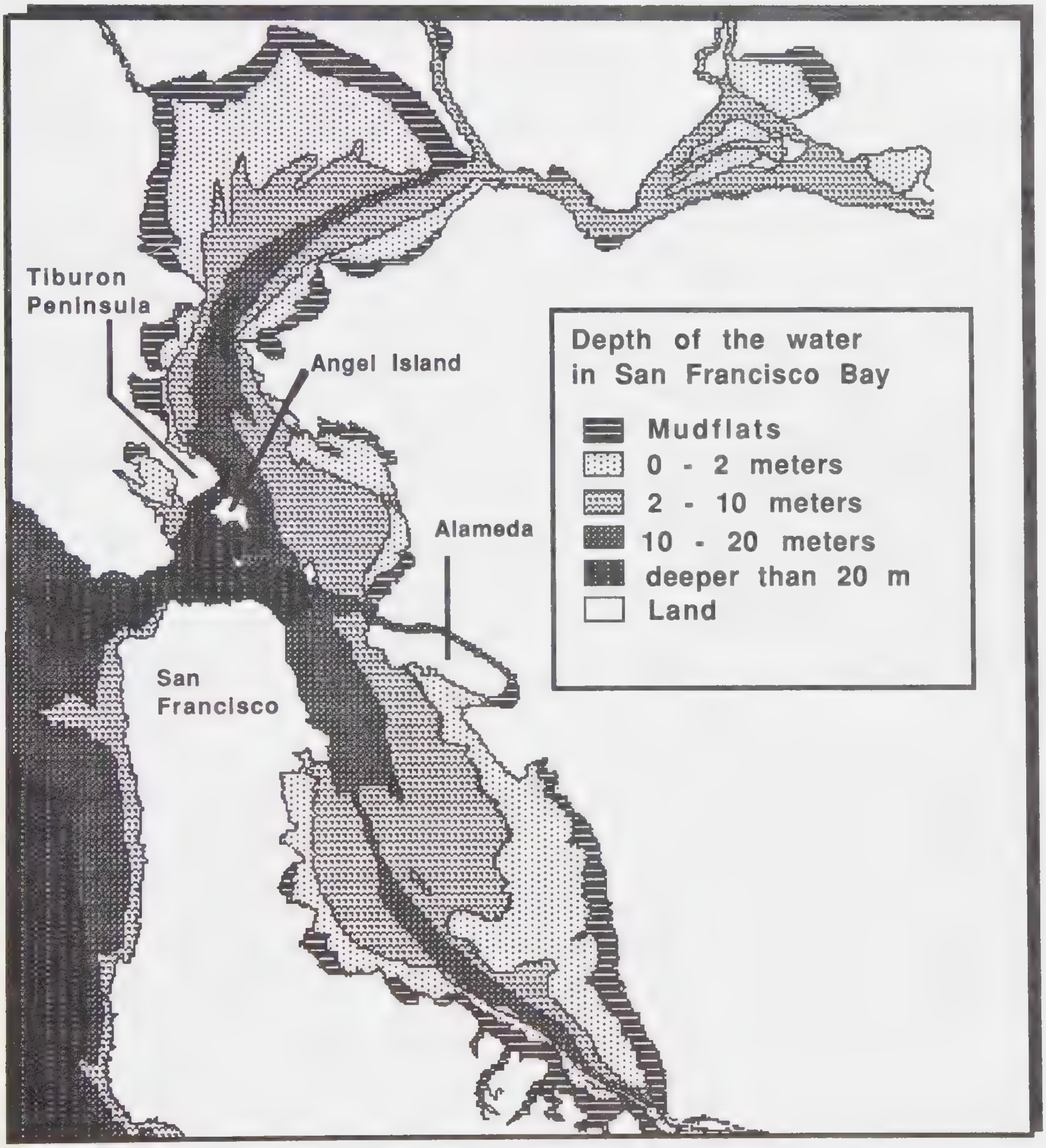
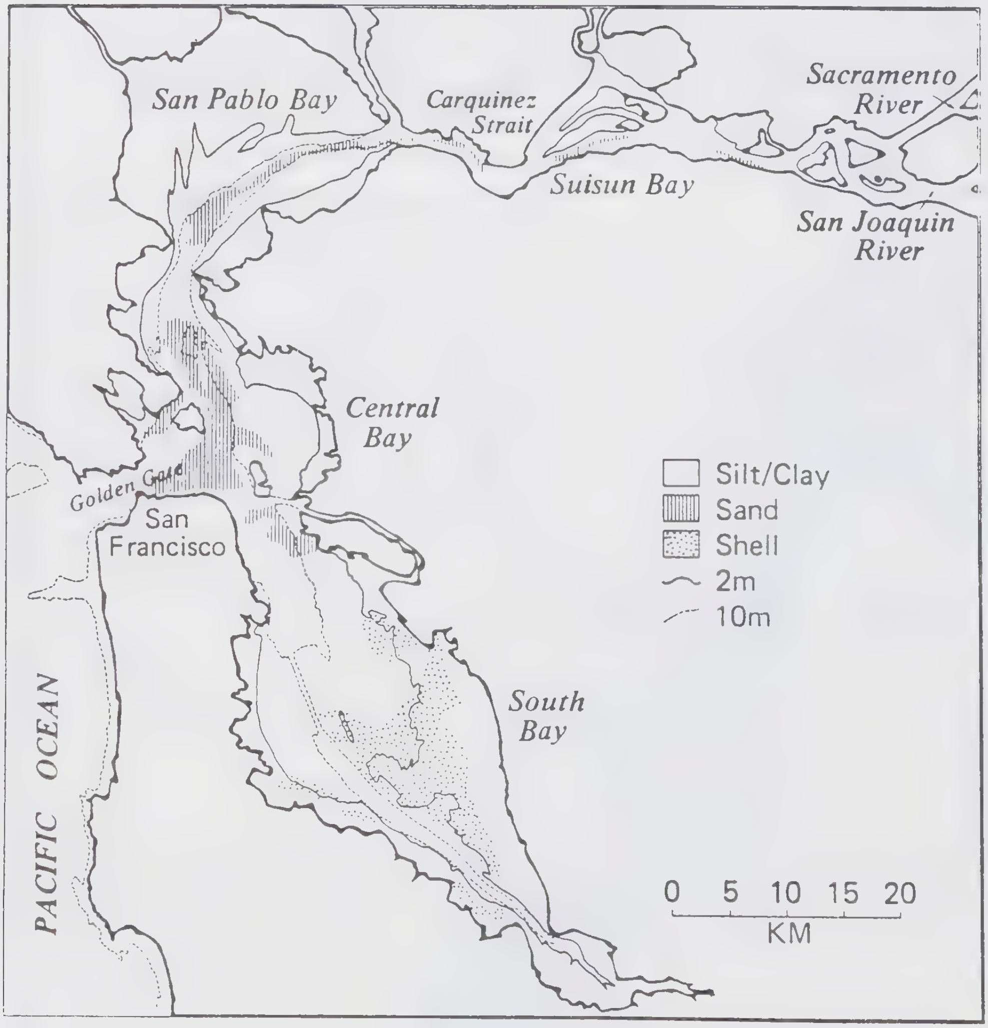


Fig. 22. Generalized distribution of surface sediment particle sizes in San Francisco Bay. After Nichols and Pamatmat (1988).



Once deposited, these fine particles enter a dynamic cycle of resuspension and deposition, induced principally by currents, tides, wind, and freshwater runoff. Consolidation of these particles after deposition, due to intermolecular attraction and the weight of overburden, increases their shear strength. These consolidated, cohesive deposits are more resistant to erosion. Currents and waves provide enough energy to erode significant quantities of deposited sediment, however, and these particles circulate through channels used for navigation. Lower current velocities in these channels, either during slack water or due to the existence of breakwaters and other structures, favor particle deposition. Maintenance dredging is required to prevent the accumulation of this fine-grained sediment in many navigation channels.

2. Distribution and Abundance of Contaminants in Sediments of the Estuary

The fine-grained sediments of urban-industrial estuaries act as a sink for many classes of pollutants, including metals, metalloids, petroleum hydrocarbons, chlorinated hydrocarbons, phthalates, and other chemical classes (Freedland *et al.*, 1976; O'Connor *et al.*, 1982; Segar and Davis, 1984; OTA, 1987). The most highly concentrated contaminants in sediments typically are those that are "sparingly soluble" in water and that have a high affinity (adsorption potential) for sedimentary material (OTA, 1987). These compound classes include conservative materials like the metals (e.g., Cd, Cu, Zn, Hg, Pb, Ag, Se, etc.), certain metalloids (e.g., As), and persistent and moderately persistent organic contaminants (e.g., DDT and metabolites, dieldrin, chlordane, toxaphene, polychlorinated biphenyls (PCBs), dioxins, and high molecular weight polynuclear aromatic hydrocarbons (PAHs) such as anthracene, benz[a]anthracene and benzo[a]pyrene). The heavy metals, chlorinated pesticides, PCBs and PAHs comprise the majority of "priority pollutants" (Callahan *et al.*, 1979), as well as the greater portion of "substances of concern" in any assessment of chemical pollution in coastal waters and estuaries (Risebrough, 1977; Mueller *et al.*, 1976, 1982; O'Connor and Stanford, 1979; Bieri *et al.*, 1982; O'Connor and Huggett, 1988; Phillips, 1988).

Contaminants from point and non-point sources enter surface waters in either the dissolved, colloidal, or particulate form. In the water column, contaminants often become associated with finely divided particulate matter through a variety of processes, including cation exchange, adsorption to solids, and partitioning (Karickhoff *et al.*, 1979; Karickhoff and Morris, 1984; Pavlou, 1984). The reason that contaminant materials associate with finely divided particles rather than with coarsely divided sediments is due to the higher exchange and adsorption potential of fine sediments, which is a function of the electrical charge on the surface of finely divided particles, and the large surface area-to-volume ratio of small particles.

The distribution of contaminants in the sediments of the Estuary reflect interactions among of a number of factors, including the source of contaminants, the affinity of pollutants for particles, and the dynamics of particle deposition, erosion, and transport (see Davis *et al.* [1989] for a detailed discussion of contaminant sources and fates in the Estuary). The San Francisco Estuary is different from other major estuaries in that particle erosion and transport plays a major role in the distribution of contaminants throughout the system. Estuaries like Puget Sound, the Hudson River,

and Chesapeake Bay do not experience wind-driven sediment resuspension of the same order of magnitude as the San Francisco Estuary. In those systems the pattern of contaminant distribution in deposited sediments more closely reflects the abundance of contaminants at individual sources. In the San Francisco Estuary the pattern of contaminant distribution derives from major sources within sub-sections of the Bay, but is modified by broad-scale transport of finely divided material within and among its major basins.

Researchers at the National Oceanic and Atmospheric Administration (NOAA) recently published an exhaustive review of trends in the concentrations of contaminants in San Francisco Bay sediment and biota (Long *et al.*, 1988). This review examined sediment data collected from 1970 through 1987 for six trace elements (mercury, cadmium, copper, lead, chromium, and silver), polynuclear aromatic hydrocarbons (PAHs), DDT and its metabolites DDE and DDD, and polychlorinated biphenyls (PCBs). Many of the sediment data reviewed by Long *et al.* (1988) were gathered from studies of dredging sites such as the Oakland Outer Harbor (USCOE, 1979), Oakland Inner Harbor (USCOE, 1983), the Alameda Naval Air Station (USCOE, 1973), and other locations (USCOE, 1976a, 1977a; U.S. Navy, 1987). (This review also included many other sources of data, such as studies of the effects of effluent discharges into the Bay, and research projects sponsored by NOAA, the U.S. Geological Survey, and the USEPA.) The database of Long *et al.* (1988) therefore includes contaminant concentrations of sediments subject to dredging and can provide a general understanding of the potential for dredging operations in the Estuary to encounter contaminated sediments. As Long *et al.* (1988) surveyed all available sediment data regardless of location within the Estuary, this database does not exclusively represent the level of contamination in sediments excavated during dredging.

Long *et al.* (1988) cited some general conclusions concerning geographic trends in contaminant distribution in San Francisco Bay. All areas of the Bay were at least slightly contaminated relative to coastal reference locations (Bodega or Tomales bays) or background levels attributable to natural sources (Table 13). They also concluded that the highest concentrations of many contaminants within the Bay (including mercury, lead, copper, silver, and PCBs) occurred in peripheral areas such as harbors, waterways, and boat basins. Only chromium appeared to be more concentrated in the sediments of open embayments. The validity of these data for chromium has been questioned in other work (Phillips, 1987). Areas with the most consistently elevated levels of contamination in sediment were China Basin, Islais Creek, Oakland Inner Harbor, Mare Island Strait, and Redwood City Harbor. Areas with the highest concentrations of contaminants overall (including measurements in both sediments and the tissues of organisms) were Islais Creek, Richmond Inner Harbor, Oakland Inner Harbor, Redwood Creek, China Basin, and the region of the Hunters Point Naval Station.

The largest maintenance dredging projects in the Estuary, Richmond Inner Harbor, Oakland Inner Harbor, and Mare Island Strait (see Section V.A.), are thus also sites of elevated contamination in sediments. Other sites showing elevated sediment contamination that have been dredged in the past, or are adjacent to areas that have been dredged, include Islais Creek Waterway, Hunters Point Naval Station, and

Table 13. Overall means and related statistics on contaminant concentrations (ug g^{-1} dry wt.) in sediments of San Francisco Bay, based on data collected by many investigators from 1970 through 1987 at depths from 1-76 cm. Adapted from Long *et al.* (1988). N = number of samples.

Contaminant	Mean (N)	Standard Deviation	Maximum	Minimum	Reference Sites: Bodega Bay	Reference Sites: Tomales Bay
Mercury	0.5 (1097)	0.67	6.80	0.01	0.14	0.3
Cadmium	1.06 (999)	1.16	17.3	0.02	0.27	0.37
Copper	51 (879)	58	1500	<1	4	42
Lead	56 (1314)	300	10^4	1	1	20
Chromium	89 (396)	96	769	8	350	230
Silver	1.13 (336)	1.52	16	<.01	0.92	0.14
Total PAH[1]	4.1 (101)	10.1	80.9	0.02	0.08	0.47
Total DDT[2]	0.10 (153)	0.28	1.96	0.25	0.00008	0.0019
Total PCB	0.11 (52)	0.17	0.82	0.006	0.005	0.004

[1] Includes only 7 PAHs measured in each of several studies: Phenanthrene; Anthracene; Fluoranthene; Pyrene; Benz[a]anthracene; Chrysene; and Benzo[a]pyrene.

[2] Does not include data on extremely contaminated sediment from the Lauritzen Canal. The overall mean including the additional 13 samples from the Lauritzen Canal is 7.5 μg g^{-1} dry weight. The mean value for Lauritzen Canal is 260.7 μg g^{-1}.

Redwood City Harbor. The data reviewed by Long *et al.* (1988) do not suggest that all ports and harbors are heavily contaminated, as contaminant concentrations in the sediments of some dredged areas were below levels in the open bays or below overall means for the Bay. The data show that the sediments of many of the navigational channels subject to dredging contain some of the highest levels of contamination measured in the Estuary.

It is important to remember that Long *et al.* (1988) did not perform an independent and random survey of sediment contamination in the Estuary, but rather summarized information available from other studies. Long *et al.* (1988) point out that previous studies have collected data in a sporadic and inconsistent manner, and the average values Long *et al.* (1988) calculate should therefore be treated cautiously as representative of contamination in sediments of the Estuary. Contaminant concentrations in sediments can vary over small spatial scales, and the actual location of sampling sites will influence average concentrations, particularly when a small number of samples is taken.

A recent examination of spatial patterns of abundance for organic contaminants in surficial sediments of the Bay and Delta provides further evidence that dredged areas contain elevated levels of contaminants (Rice *et al.*, in press). These authors measured concentrations of 13 PAHs, 8 pesticides, 11 PCB congeners, and benzthiazole (a proposed tracer of urban runoff; see below) at 18 sites. In general, they found that sediments in enclosed waterways were "heavily contaminated" by these persistent and toxic compounds, which is not surprising as such sites are often close to point and non-point sources of pollution and are characterized by low current velocities that favor particle deposition. The total PAH concentrations measured at Islais Creek and India Basin (along the western shore of Central Bay), Port of Stockton, and Mormon Channel (in the Southern Delta) are among the highest reported on the Pacific Coast (Table 14). The sample from Islais Creek contains the highest level of PAHs recorded to date in sediments from the Estuary. Total PCB concentrations reported by Rice *et al.* (in press) at several sites in the southern Delta were also among the highest reported on the Pacific Coast, and the value for Mormon Channel is the highest recorded in the Estuary.

These PAH and PCB concentrations are comparable to concentrations measured in other urban estuaries (Bieri *et al.*, 1982; O'Connor *et al.*, 1982; O'Connor and Huggett, 1988). Total PAH in Newtown Creek (Brooklyn, New York), for example, was 182 $\mu g\ g^{-1}$ (dry wt.), comprised primarily of naphthalene (O'Connor *et al.*, 1982). In the southern branch of the Elizabeth River, Virginia, PAH concentrations in excess of 100 $\mu g\ g^{-1}$ (dry wt.) were reported by Bieri *et al.* (1982); the greatest proportion were three- and four-ring compounds such as phenanthrene, fluoranthene, and pyrene.

PCB concentrations in urban estuaries of the Eastern U.S. range from low values in sandy sediments to "hot spots" of greater than 50 $\mu g\ g^{-1}$ (dry wt.) in deposits of fine material. Typical PCB concentrations in New York Harbor fine sediments range from about 2 to 10 $\mu g\ g^{-1}$ (dry wt.) (O'Connor *et al.*, 1982), but show great variability from site to site depending upon local contaminant sources (MacLeod *et al.*, 1981; O'Connor *et al.*, 1982).

Table 14. PAH and PCB concentrations in surficial (top 1-5 cm) sediments from the San Francisco Estuary (Rice *et al.*, in press).

Compound Class	Location	Concentration in sediment $\mu g\ g^{-1}$ dry wt.	Concentration in sediment $\mu g\ g^{-1}$ Organic carbon
ΣPAHs	Islais Creek	129	36,300
	India Basin	69.7	23,200
	Port of Stockton	47.5	26,500
	Mormon Channel	73.5	24,400
	Mormon Slough	1.4	1,600
ΣPCBs	Islais Creek	0.45	125.0
	India Basin	0.78	259.0
	Port of Stockton	12.6	7,020
	Mormon Channel	17.8	5,913
	Mormon Slough	7.1	8,060

Benzthiazole is a component of weathered rubber that has been suggested as a chemical marker for street runoff (Spies *et al.*, 1987). Rice *et al.* (in press) found high concentrations of this compound in many of the waterways that are adjacent to bridges and roadways (as ports and harbors often are), implicating urban runoff as a source of some of the contamination of sediments found in these areas.

Data collected recently in Oakland Inner Harbor also provides further evidence that urbanized and industrialized ports and harbors are often sites of extreme contamination. Bulk sediment analyses of samples collected in December 1986 from Oakland Inner and Outer harbors showed that a site in the Inner Harbor near Schnitzer Steel Company exhibited high levels of contamination (USCOE, 1988a). Concerns were raised in comments on the Draft Supplemental Environmental Impact Statement (SEIS) for the Oakland Harbor project about the quality of sediments in this area. Consequently, additional testing was performed on these sediments for the Final SEIS (USCOE, 1988a).

Figures 23(a) and 23(b) portray contaminant levels measured in sediment near Alameda Gateway (formerly Todd Shipyard), which is situated across the Inner Harbor channel from Schnitzer Steel. Concentrations of each contaminant at each of four sampling sites are shown as bars in Fig. 23. At present there are no objective criteria that may be used in judging the significance of reported contaminant concentrations in sediment (see Section V.E. for a thorough discussion of sediment testing requirements and procedures for interpretation of test results). The overall statistics of Long *et al.* (1988) can be used as less desirable, but nevertheless constructive, criteria to assess the relative degree of contamination of different sediments. In Figs. 23(a) and 23(b), each group of bars is wholly or partially enclosed by a box with three horizontal lines that represent (in ascending order): the Bay-wide mean; the mean plus 2 standard deviations (approximating the Bay-wide 95th percentile); and the maximum value recorded by Long *et al.* (1988). Bars in Figs. 23(a) and 23(b) exceeding the second line may be considered high concentrations; those exceeding the top line are higher than any recorded from studies of sediments between 1970 and 1987, as reported by Long *et al.* (1988). Other contaminants were measured by USCOE (1988a) in these Oakland Harbor samples but are not included in Figs. 23(a) and 23(b) because Bay-wide means were not available.

Figure 23 shows that sediments from the four sites in Oakland Inner Harbor exhibit elevated concentrations of mercury, total PCBs, chromium, copper, and total PAHs. Several values from this area (all data measured in dry weight) are higher than the maxima reported by Long *et al.* (1988), including: 8.3 $\mu g\ g^{-1}$ mercury at site T5; 1.37 and 1.44 $\mu g\ g^{-1}$ total PCBs at sites T6 and T7, respectively; and 930 $\mu g\ g^{-1}$ chromium at site T6. (The level of total PCBs is still almost an order of magnitude less than the values measured by Rice *et al.* (in press) in Mormon Channel [Table 14].) Additional sampling in March 1988 of five sites in the turning basin near Schnitzer Steel and Alameda Gateway (Word *et al.*, 1988) again measured elevated concentrations of total PCBs at 3 of the 5 sites (up to 780 $\mu g\ g^{-1}$); chromium at 2 sites (up to 425 $\mu g\ g^{-1}$); and copper at 2 sites (up to 183 $\mu g\ g^{-1}$). Levels of mercury and total PAHs, however, were lower in these samples than in those collected earlier.

Fig.23 (a). Comparison of the concentrations of cadmium, mercury, silver and total PCBs in sediments from four sites in Oakland Inner Harbor (USCOE, 1988a) with Bay-wide statistics computed by Long *et al.* (1988). Bars representing concentrations from Oakland Inner Harbor are wholly or partially enclosed by boxes with three horizontal lines that represent (in ascending order): the Bay-wide mean; the mean plus 2 standard deviations (approximating the Bay-wide 95th percentile); and the maximum value recorded by Long *et al.* (1988). Numerical values are provided where the data exceed the maximum on the vertical axis.

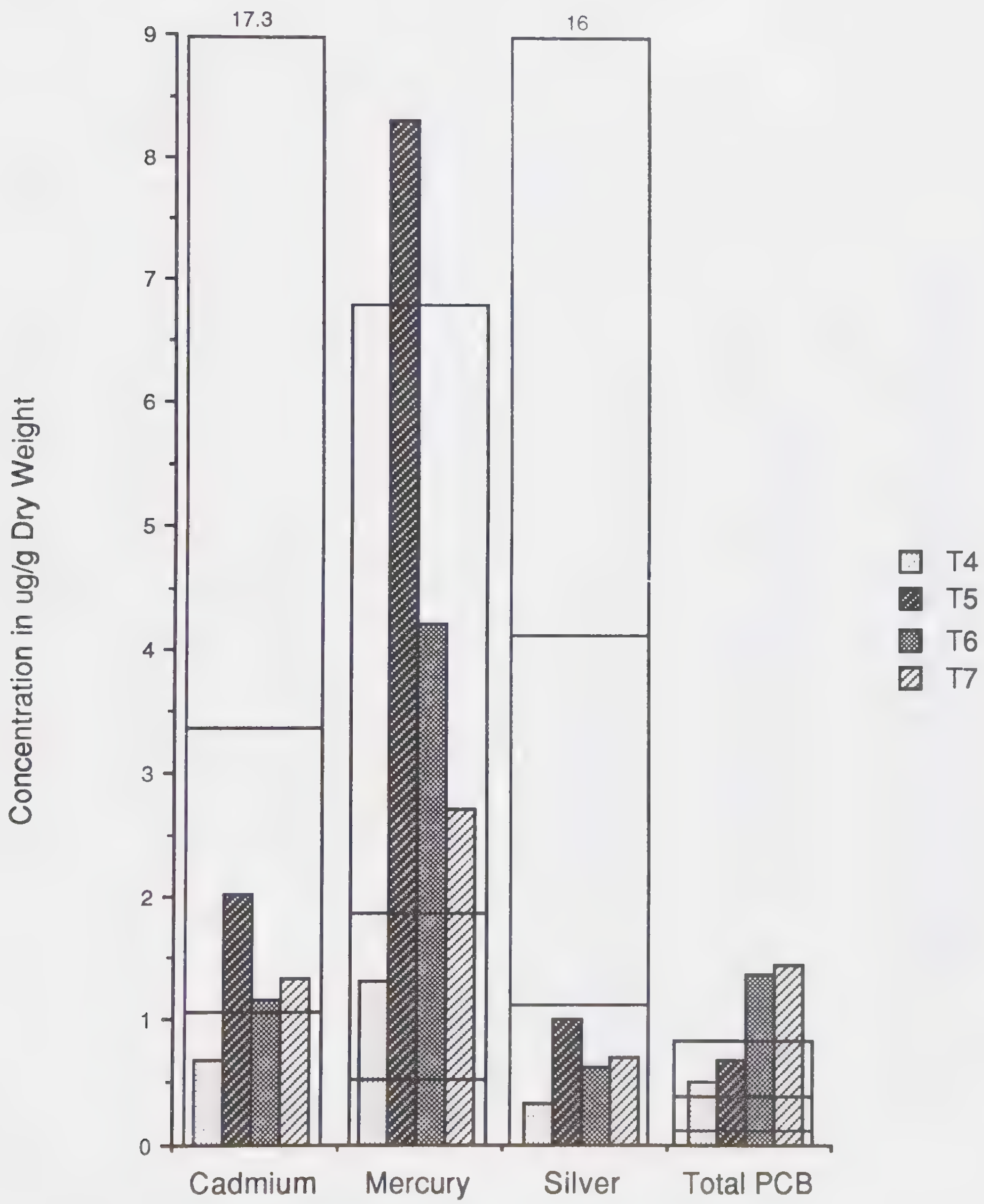
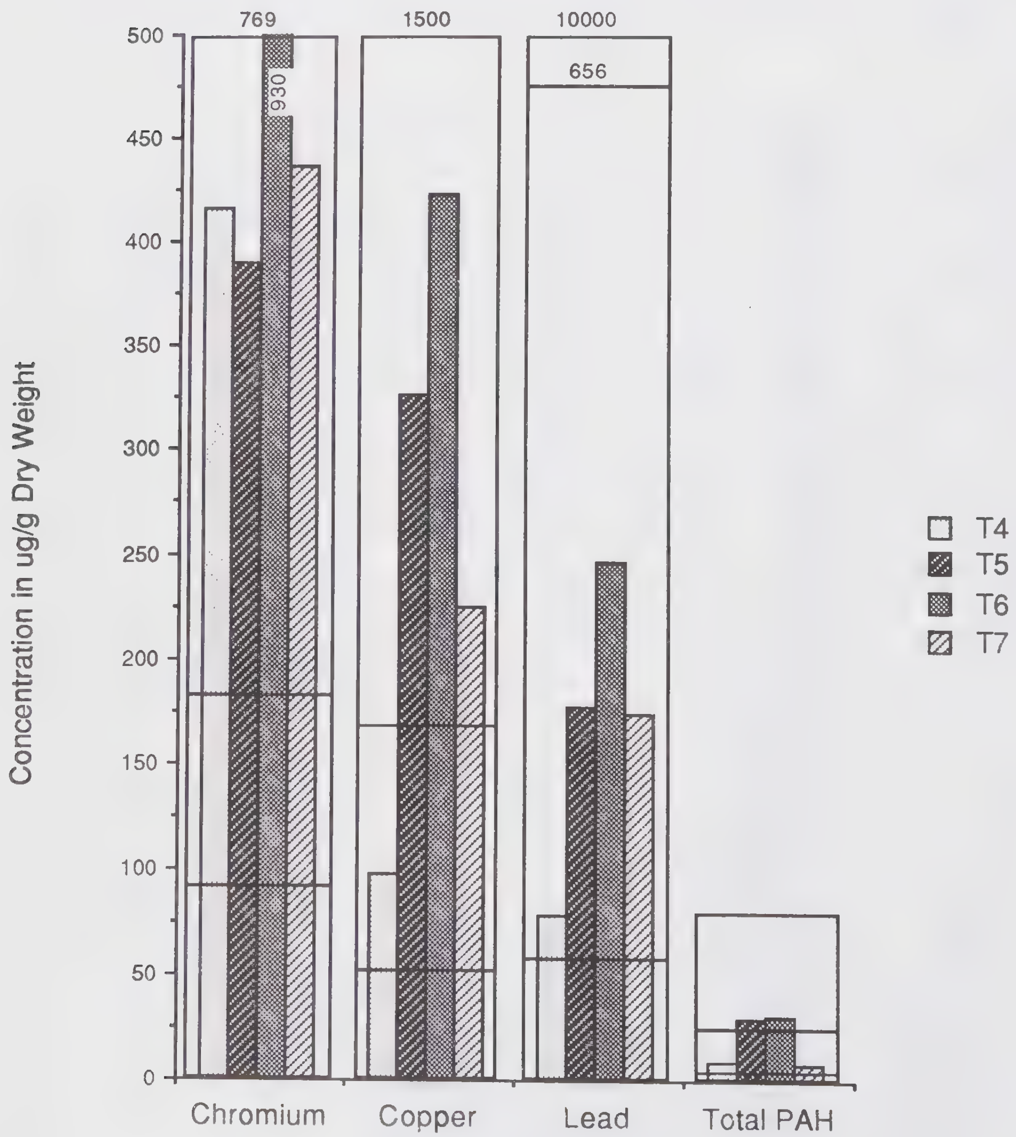


Fig.23 (b). Comparison of the concentrations of chromium, copper, lead and total PAHs in sediments from four sites in Oakland Inner Harbor (USCOE, 1988a) with Bay-wide statistics computed by Long *et al.* (1988). Bars representing concentrations in Oakland Inner Harbor are wholly or partially enclosed by boxes with three horizontal lines that represent (in ascending order): the Bay-wide mean; the mean plus 2 standard deviations (approximating the Bay-wide 95th percentile); and the maximum value recorded by Long *et al.* (1988). Numerical values are provided where the data exceed the maximum on the vertical axis.



USCOE measured TBT in 6 of 7 sediment samples taken near Schnitzer Steel and Alameda Gateway, with a maximum concentration of 0.582 $\mu g\ g^{-1}$ (dry wt.). Word *et al.* (1988) measured 1.907 $\mu g\ g^{-1}$(dry wt.) of TBT in sediments at one site in this area, which exceeded the highest concentration observed in the earlier sampling. In comparison, the most extensive survey to date of TBT concentrations in sediments of California coastal waters (Stallard *et al.*, 1987), which included many marinas in the Bay and Delta, did not find any sediment concentrations greater than 0.023 $\mu g\ g^{-1}$ (dry wt). It should be noted that standard methods for determining organotin concentrations in sediment have not been established, so results obtained from the different laboratories mentioned here may not be strictly comparable. The lack of standard reference materials for TBT in sediments also makes it difficult to judge precisely the accuracy of laboratory measurements. The variation between the two rounds of sampling also probably reflects small-scale spatial variation in the Harbor.

These results confirm that elevated quantities of contaminants are present in the Oakland Inner Harbor. The USCOE judged these sediments from Oakland Inner Harbor to be contaminated to a degree that necessitated special handling upon disposal. An ocean disposal alternative was favored in the Final SEIS, in which these contaminated sediments would be capped by other cleaner sediments (USCOE, 1988a).

In summary, the available data on contaminant concentrations in sediments of the San Francisco Estuary suggest that, in general, ports and harbors can be sites of extreme sediment contamination. Available data also indicate that concentrations can vary on a small spatial scale. Several of the areas of San Francisco Bay in which significant amounts of dredging occur (e.g., Mare Island Strait, Richmond Harbor, Oakland Harbor) are known to exhibit elevated concentrations of many contaminants in sediments compared to more open regions of the Estuary, or to reference stations outside the Estuary. Three factors contribute to this phenomenon. First, important local sources of contaminants are or have been historically present in such urbanized and industrialized locations. Second, the characteristic low current velocities in these locations favor the deposition of fine particulate material. Third, the surface charge of these small particles and the relatively large surface area that they provide for sorption of contaminants results in higher concentrations of contaminants being found in such fine sediments. Given the elevated concentrations of contaminants present at some dredging sites in the Estuary, the potential exists for adverse effects upon estuarine biota due to the release of these contaminants during disposal of dredged material. This topic is considered further in Section V.D. of the present report.

C. FATE OF DISPOSED DREDGED MATERIAL

1. Introduction

The fate of disposed dredged material in the San Francisco Bay and Delta is influenced by a variety of factors, including the physical and chemical characteristics of the dredged material, the physical characteristics of the disposal site, and the hydrography of the Estuary (tides, freshwater inflows, and wind-driven currents; Holliday, 1978). As discussed above (Section II) the sediments in the Estuary are highly dynamic; dredging and disposal activities are part of a complex system of sediment transport and deposition that is not well known. Increased understanding of the fate, transport, and disposition of disposed dredged material in the Estuary is critical for at least three reasons: 1) In order to better understand the problems of dredge material mounding at the Alcatraz Disposal Site; 2) In order to better understand the potential for sediment-associated contaminant transport throughout the Estuary; and 3) In order to better manage dredging by understanding the cycling of dredged material from disposal sites back to dredging projects.

The fate of disposed dredged material in the Estuary can be studied in three ways. First, the movement of suspended and deposited dredged material can be studied in the field using direct sampling of suspended solids, sonar, drifters, tracers, and other tracking tools. Such studies are limited because they examine the movement of materials only under the conditions that prevail at the time of the study. They can, however, provide important information in the short term. Iridium (Ir) tracer studies, for example, identified the recycling of disposed dredged material from the Carquinez Disposal Site back to Mare Island Strait (USCOE, 1976c), and SAIC (1987b) used side-scan sonar to track the dispersion of disposed dredged material at the Alcatraz site.

Second, the fate of disposed dredged material may be studied using physical models such as the San Francisco Bay Physical Model (SFBPM), located in Sausalito, CA. A physical model is a scale model designed to simulate water movement in the system under study. USCOE has constructed a number of physical models of major ports and harbors in the United States. The advantage of using a physical model to study the Estuary is primarily that of control. Properly designed experiments with physical models can generate more data on water movement in certain portions of the Estuary over a period of days than can be accumulated from field studies in several years. The disadvantages to using a physical model, however, are many. Perhaps most important, the physical model is limited in size to a small portion of the Estuary, and there is a problem in accurately reproducing estuarine particle behavior on the greatly reduced scale of the physical model. Furthermore, the physical model was not designed for studies with particulate matter.

A third means for studying the fate of disposed dredged material in San Francisco Bay is the construction of numerical or mathematical models that combine theoretical considerations of water flow and particle behavior with experimental observations of particle transport in the field. Properly designed, such models combine the most important hydrographic and physical characteristics of the system with the best available data on disposed sediment behavior to generate profiles of

sediment transport and deposition in the Estuary over time. When such a model is calibrated and verified, it can be a valuable tool for understanding the causes of observed variations and the effects of various management strategies on the disposition of dredged material. The disadvantages of working with numerical models are that even the best numerical model is only as good as the data used in its initial formulation, and the predictions of the model must be verifiable in field studies. Good hydrographic data on the San Francisco Estuary are sparse, and, although numerical sediment transport models have been created, none as yet have been verified in the San Francisco Estuary.

This Section reviews the factors that affect the fate of dredged material disposed in the Estuary. The models being developed by the USCOE to analyze these issues will be described, and the results produced by them will be evaluated. Data on the initial dispersion of disposed dredged material and the resuspension and transport of dredged material are reviewed. A sediment budget for the Alcatraz disposal site is also critically reviewed. Results of a tracer study are presented, and the implications of this work and other calculations regarding the transport of disposed material back to dredging sites are described.

2. Model Development

Modeling the fate of dredged material disposed in the Estuary requires an understanding of hydrodynamics, the behavior of dredged material when it is dumped, and factors that control the longer term transport of sediments. The USCOE is developing an integrated numerical model (*TABS-2*; Pankow, 1988), that combines three sub-models, one for hydrodynamics (Two-Dimensional Model for Open Channel Flows; of *RMA-2V*), another for disposal (Discharge from an Instantaneous Dump; *DIFID*), and the last for sediment transport (Sediment Transport in Unsteady Two-Dimensional Flows, Horizontal Plane; *STUDH*). *TABS-2* utilizes these submodels in a sequential manner, the output from each of them providing input to the next phase of the *TABS-2* as it runs.

RMA-2V is a hydrodynamic model that predicts currents in an area stretching from 11 km west of the Golden Gate into South Bay and to the Carquinez Strait at 5,000 separate points over time. *RMA-2V* accounts for the effects of land masses, bathymetry, and turbulent mixing to produce a vertically averaged current at 37-minute intervals, with particularly detailed currents being estimated in the vicinity of the Alcatraz disposal site. As with any mathematical model, the *RMA-2V* model approximates conditions in the Bay. The model is two-dimensional in nature; predicted currents are thus vertically averaged. Estimating vertically averaged current velocities simplifies the natural situation in the Bay, in which currents move in different directions at different depths. In addition, *RMA-2V* (as applied to date for San Francisco Bay) reproduces tidal currents only and does not examine non-tidal phenomena such as wind-driven currents, which can be important in the Estuary, particularly on a local scale in the shallow reaches. The *RMA-2V* model was verified using both a 19-year mean tide simulation and a simulation of an extreme spring tide. Comparisons were made between the tides in the Bay Model and the predictions of the numerical model at 10 tide stations and 13 current velocity stations. The general agreement was good,

with the current velocities predicted by the numerical model being slightly small than those observed in the Bay Model.

The tidal velocities generated by the *RMA-2V* hydrodynamic model are used as input to *DIFID*. *DIFID* is a three-dimensional model; the vertically averaged tidal velocities from *RMA-2V* are distributed into three dimensions using numerical techniques. *DIFID* simulates the actual disposal of dredged material, including its descent through the *RMA-2V* water column, impact with the bottom (or with the thermocline), and initial spreading. The model separates the disposed material into fractions of different densities and produces suspended sediment concentrations in three dimensions within the modeling grid. As *DIFID* does not include predictions relating to the erosion and transport of settled material, it can only be used to understand the fate of disposed dredged material over a short period subsequent to the disposal event. Recent DIFID simulations performed by USCOE covered a period of about 16 minutes (Trawle and Johnson, 1986).

The *DIFID* model produces suspended sediment concentrations in a three-dimensional grid based upon the expected behavior of disposed dredged material at an aquatic site. However, *DIFID* has not been verified using data from the Bay (Pankow, 1988); results from application of the model to the Bay should only be considered preliminary (Bowen, 1976). Furthermore, *DIFID* describes the behavior of disposed dredged material on impact with a flat or sloped bottom, but not for a mound, which is the existing condition of the substrate at the Alcatraz disposal site. Finally, as applied to date, *DIFID* has not accounted for hindered settling of particles at the sediment-water interface (Trawle and Johnson, 1986); the model has been recently upgraded to include this phenomenon (W. McAnally, USCOE, personal communication).

The output of the *DIFID* model is used as input to *STUDH*. *STUDH* predicts the transport of both noncohesive (coarse) and cohesive (fine) particles and models both deposition and erosion phenomena. *STUDH* is in the preliminary stages of development and has not been calibrated or verified for the San Francisco Bay. However, published tests to date for *STUDH* have indicated the feasibility of linking this sediment transport model with the hydrodynamic and disposal models discussed as part of the overall *TABS-2* model. It has been shown that *STUDH* can simulate the two-dimensional movement of a sediment cloud for 3.75 hours after disposal, but the erosion and deposition portions of the model have not yet been verified (Pankow, 1988; W. McAnally, USCOE, personal communication).

Utilizing this sequential input from sub-models, *TABS-2* has the potential to provide useful information regarding the fate of dredged material disposed at the Alcatraz site over several tidal cycles. The coupling of hydrodynamic, disposal, and sediment transport models is critical if the complexities of dredged material disposal and transport are to be adequately described in a numerical model. Such a "combined" model allows for the detailed examination of the impact of a variety of proposed management schemes on the short-term fate of disposed material. The developers of the *TABS-2* model have made significant progress on this exceedingly difficult task.

It has yet to be verified, however, that the integrated *TABS-2* model can accurately predict the movement of dredged material or suspended sediment at Alcatraz. Two key limitations of the model need to be addressed. The first limitation is that the integrated model is principally two-dimensional in nature. It is known that residual currents (water movements net of the tidal cycle) vary significantly with depth at the area of the Golden Gate, with net surface currents being predominantly seaward, while net near-bottom currents are predominantly landward throughout the tidal cycle (see Section below). This factor is likely to be critical in determining the direction of transport of material disposed of at the Alcatraz site. The modeling approach is currently being modified to simulate the effect of changing current velocities with depth, which will help to address the key questions regarding the fate of disposed material in the Estuary.

The second limitation is that *TABS-2*, as applied to date, has not allowed for the effect of sediment resuspension and redeposition in the Estuary, i.e., it has not covered long-term transport phenomena. It is believed that sediment mobility is generally high within the Bay (Nichols and Thompson, 1985b; SAIC, 1987a), presumably because of the impacts of both tidal currents in deeper waters and wind-induced currents in shallower regions of the Bay. The long-term transport of fine sediments in the Estuary is a particularly challenging area of study and is recognized as a critical factor in evaluating the effects of within-Bay disposal of dredged material. It should be noted that the fine material will not only be that fraction most easily transported away from the disposal site, but will also generally constitute the most contaminated material (as the contamination of sediments usually varies inversely with grain size).

The uncertainties associated with the predictions of complex models such as *TABS-2* are not easily quantified. This is especially true when verification procedures do not include a simulation of field data from the Estuary in order to judge the ability of the model to simulate natural processes (i.e., model coefficients are not adjusted). A simulation of this kind would allow the accuracy of model predictions to be directly measured via comparison to field data. This would provide an understanding of the absolute error in model predictions, which is important if the *TABS-2* model is applied to analyzing the impact of alternate management strategies.

Uncertainty also arises from the fact that the models include many non-linear equations, and small changes or inaccuracies in particular parameters can result in large effects upon model predictions. An important step for building confidence in complex models is a sensitivity analysis, during which key parameters (including boundary conditions) are varied. Confidence in model predictions can thus be increased by ensuring that accurate input data are used for the sensitive parameters. Sensitivity analysis of the *TABS-2* model is not documented in the publications cited in this report.

Despite its limitations, the modeling work of the USCOE, and particularly some of the results of the DIFID disposal model, provide a basis for understanding the initial dispersion of dredged material after dumping, as well as the generation of the mound of dredge spoils at the Alcatraz dump site. This information will be reviewed in the next Section and will be followed by a discussion of the erosion, transport, and ultimate fate of sediments disposed in the Estuary.

3. Initial Dispersion of Disposed Dredged Material

Dispersion during the disposal of dredged material includes advective (circulation) and diffusive (mixing) processes. A variety of factors affect the initial dispersion of dumped material, including characteristics of the dredged material (grain size, moisture content, cohesion, etc.). Other factors include the speed of the disposal vessel, the manner of disposal (i.e., split hull barges *vs.* hopper dredges, etc.), and the depth, density, and movement of waters at the disposal site.

The initial behavior of dredge material after dumping occurs in three phases; 1) convective descent, 2) dynamic collapse, and 3) passive diffusion (Gordon, 1974; Bowers and Goldenblatt, 1978; Fig. 24). These phases form the basis for the *DIFID* model and field studies have supported this theoretical description (Gordon, 1974; Tovolaro, 1984; Truitt 1986b; SAIC, 1987b, 1987c). During convective descent, the movement of the disposed material is controlled by gravity, and the material descends in a dense cloud or jet. SAIC (1987b, 1987c) determined the average downward velocity of material disposed at the Alcatraz site to be 1.1 m sec^{-1}.

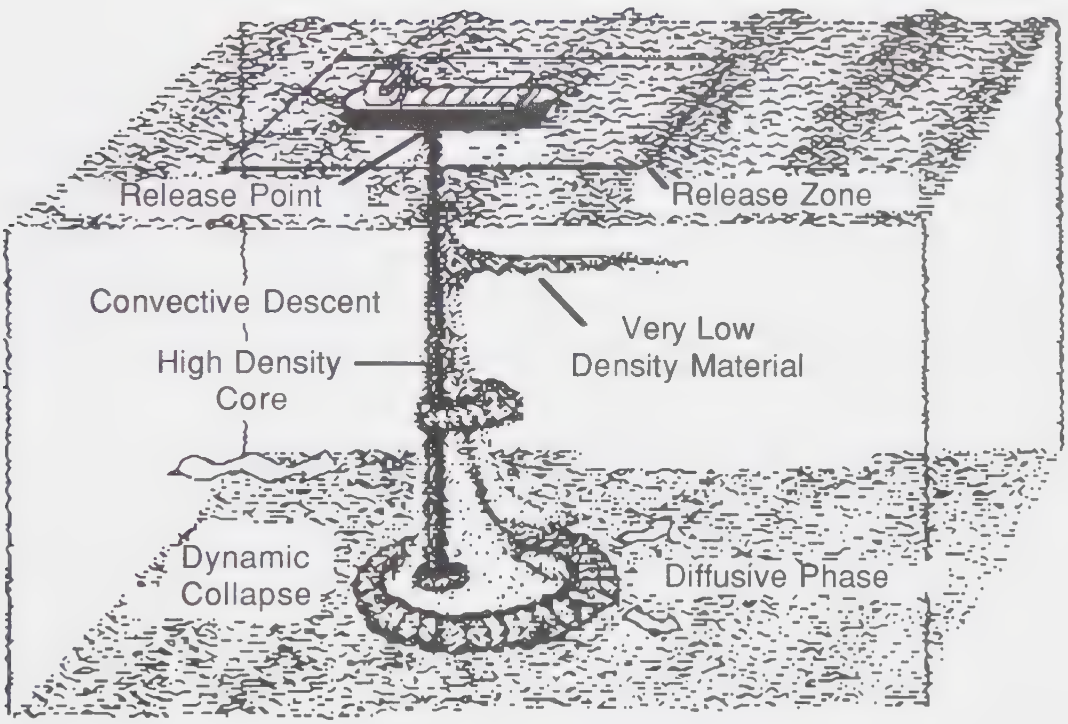
Included in the descending cloud are dense clumps of material that will reach the substrate relatively unchanged and less dense fractions that will entrain water during their descent. A small percentage (1-5%) of the less dense material will be entrained in the upper water column and transported away from the site in surface currents.

Upon striking the substrate disposed dredged material undergoes dynamic collapse. Consolidated material forms a mound, while less dense material will spread to produce a spheroid-shaped area of highly concentrated suspended solids. During dynamic collapse, horizontal movement predominates and produces a significant cloud of suspended sediment near the bottom of the water column. This cloud of suspended material surges outward from the site of impact until the kinetic energy of the fluid mass is dissipated to the point that individual particles begin to settle out (Bokuniewicz *et al.*, 1978). Larger and denser particles such as sand will settle out at velocities up to 100 times greater than those of clays and silts (Teeter, 1987).

After the energy of the surging cloud has dissipated, the movement of the disposed material is controlled by diffusion and bottom currents. During this phase, referred to as "passive diffusion," suspended sediments are transported and settle as dictated by ambient conditions of water velocity and turbulence. The denser portions of the cloud, known as fluid muds or "fluff," will flow along the bottom and will consolidate very slowly (Barnard, 1978). The slow rate of settling and consolidation in fluff is due to the phenomenon of hindered settling. Fluid muds and other material initially deposited may be eroded and transported away from the disposal site, depending upon the degree of cohesion (and later consolidation) of the deposits and the local current velocity.

During the selection of disposal sites in the Estuary, it was thought that the local current regime at the Alcatraz disposal site would provide sufficient energy to erode and disperse any consolidated sediments that were deposited at this site. Indeed,

Fig. 24. Phases of transport during open-water disposal of dredged material. After Truitt (1986b).



Sustar (1982) suggested that the capacity of the Alcatraz site to disperse disposed material was virtually unlimited. That did not, however, prove to be the case. In 1982, the USCOE determined that enough material had accumulated at the Alcatraz site to pose a hazard to navigation. A sounding of the site in early 1984 indicated that a mound existing on the eastern side of the site had risen to -8.5 m (-28 ft) at MLLW (Fig. 25) from the site's original depth of 36.5 m (120 ft; see BCDC, 1988a). Although the cause of mounding at the Alcatraz is not completely understood, it is clear that the disposal of more cohesive sediment in recent years from clamshell dredging operations reduced erosion and transport of material away from the site. The disposal of some construction debris also contributed to the problem (M. Palermo, USCOE, personal communication).

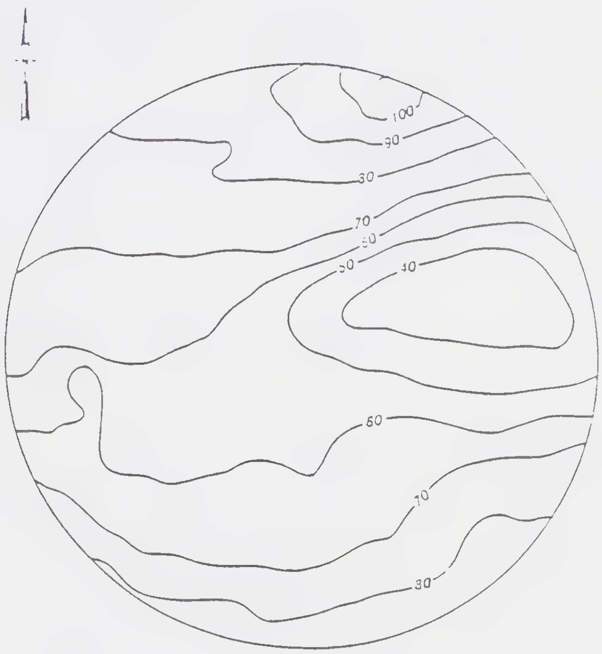
Consequently, the USCOE dredged the Alcatraz site on five occasions between July 1984 and April 1986, removing about 183,000 yd^3 (140,000 m^3)of material (USCOE, 1989a). It is not clear whether this material was removed to an upland site (SFBRWQCB, 1988; M. Carlin, SFBRWQCB, personal communication) or moved to another part of the Alcatraz dump site (USCOE 1988c, 1989a). In 1986, the mound had risen to a depth of about -12 m (-40 ft) in the northern portion of the disposal site. It was generally elliptical in shape, with the major axis running from east to west (SAIC, 1987b, 1987c). This shape conforms to that predicted by theoretical considerations of particle settling in the local hydrological regime, where the major tidal currents run in an east-west direction.

The USCOE applied the *DIFID* model to disposal operations at the Alcatraz site to estimate the percentage of disposed material initially deposited on the bottom. These studies (Trawle, 1986; Trawle and Johnson, 1986; Teeter, 1987) also included calculations and laboratory experiments to investigate the erosion and resuspension of deposited material, the results of which will be discussed in the following Section.

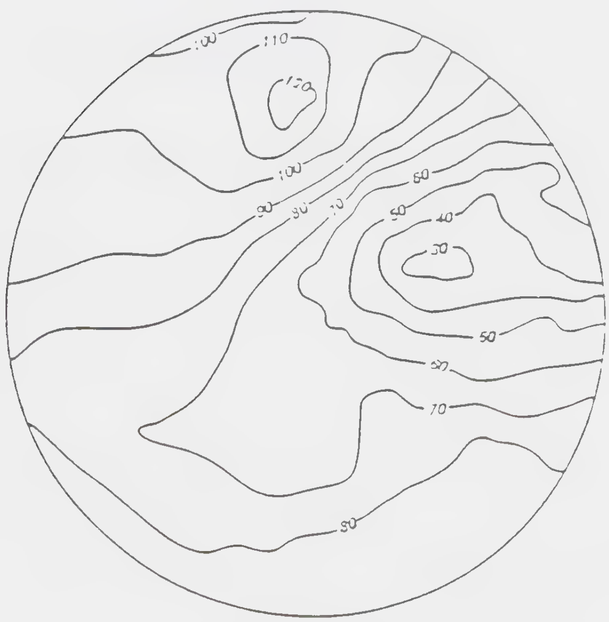
The modeling studies indicated that 18-29% of the sand, 9-12% of the silt-clay, and 99-100% of the consolidated "clumps" in a simulated disposal event would be initially deposited at the Alcatraz disposal site (Trawle and Johnson, 1986). The range of estimates for each fraction depended on the specific characteristics of the various dredged material sources investigated. All simulations were conducted under maximum ebb conditions.

Under different tidal conditions, the model predicted that the percentage deposition of disposed materials would change. This was indicated in a companion study (Trawle, 1986) in which the disposal event was modeled during ebb tides, flood tides, or the entire tidal cycle. It should also be noted that these latter model studies employed sediment characteristics typical of sediment samples from Oakland Inner and Outer Harbors and Richmond Inner Harbor to demonstrate the effect of grain size on initial dispersion. These sediments vary from 13% silt-clay for Oakland Outer Harbor to 90% silt-clay for Richmond Inner Harbor. The simulations indicated that minimum dispersion occurred during flood conditions, while maximum dispersion occurred during ebb conditions. The results also indicated that the disposal of sediments with higher sand contents resulted in a greater deposition in the disposal site for any given tidal condition.

Fig. 25. Soundings of the Alcatraz disposal site. After Trawle and Johnson (1986) and Trawle (1986).



Alcatraz disposal site bottom contours, in ft, from the 12 April 1985 survey



Alcatraz disposal site depth contours from 11 January 1984 survey (soundings in ft mllw)

While these quantitative estimates are instructive, their accuracy is difficult to determine because the *TABS-2* model has not been verified against actual conditions in the estuary. Although the most important model parameters have been altered to reflect conditions in the Bay, these alterations are based upon laboratory experiments (Trawle and Johnson, 1986). A sensitivity analysis in which model parameters are varied over a reasonable range has not been presented; hence, the percentage deposition values cited above should be considered preliminary in nature.

It should also be kept in mind that the formation of the mound must have included a "positive feedback" loop that accelerated its formation. As the mound developed, it effectively shortened the phase of convective descent for material disposed directly above it; thus, there would be less time for the more consolidated disposed materials to entrain water prior to striking the bottom. This would effectively increase the density of material on the bottom, producing deposits that would be more resistant to erosion. In turn, the size of the mound would increase, closing the positive feedback loop by further reducing the time of convective descent during subsequent disposal events.

In the summer of 1986, SAIC monitored the disposal at Alcatraz of what was estimated to be 280,000 yd^3 (214,000 m^3) of silty-clay material dredged by clamshell from the San Rafael Channel (SAIC, 1987b). USCOE (1989a) determined the actual quantity dredged to be 197,750 yd^3 (about 151,000 m^3), based upon a post-dredging bathymetric survey. Many parameters were measured by SAIC, including currents at several depths, turbidity, precise bathymetry, density of the sediments before and after disposal, and sediment plume movements. From precise bathymetry measurements before and after the month-long disposal operation, this study determined that approximately 77,500 yd^3 (59,000 m^3) of disposed material remained at the disposal site. The precise location for this study was in the Southern part of the Alcatraz site, separate from all other concurrent disposal operations. Using the density measurements of SAIC (1987b) to convert to a mass basis, the material remaining at the Alcatraz site represents about 40% of the sediments dredged during the operation.

In a companion study, which concerned the disposal of material dredged from the Richmond Channel by a hopper dredge over a three-week period in October 1986 (SAIC, 1987c), approximately 12% of the disposed material appears to have remained at the Alcatraz site. A separate post-dredging survey was not performed during this project, and the calculation relies upon the total volume dredged as deduced by SAIC (1987c) from the volume and density of hopper loads; this may in fact represent an overestimate of the actual amount dredged. The volume of the residual material has been adjusted for density differences as described by SAIC (1987c). As the hydraulic dredging technique used in the Richmond Channel project produces dredged material with a higher moisture content than the clamshell operation described above (SAIC, 1987b), it would appear that dispersion of this material was enhanced and mounding at the Alcatraz site correspondingly reduced. However, these estimates of the fraction of disposed material retained at Alcatraz are only approximate due to variations in sediment density and uncertainty in actual quantities dredged.

In an earlier study, the USCOE also examined the fate of materials disposed at the Carquinez disposal site. In this experiment (USCOE, 1976c), dredged material

was tagged with the element iridium (Ir) prior to its disposal. After disposal, sediments over a large portion of San Pablo and Suisun bays were sampled for Ir in order to monitor the transport of disposed material. This study showed that the dredged material disposed at the Carquinez site was dispersed widely throughout the study area. No mounding was detected at the Carquinez site, nor has there been evidence for mounding at the disposal site in San Pablo Bay (BCDC, 1988a). It is possible, however, that some mounding may have been occurring recently at the Carquinez site (M. Carlin, SFBRWQCB, personal communication). The differences in the degree of mounding experienced at the three disposal sites in the Bay have been suggested to be a function of the greater volumes disposed of to Alcatraz, and the fact that larger amounts of clamshell-derived dredged material are disposed to the Alcatraz site (SFBRWQCB, 1988).

4. Resuspension and Transport

Given the dispersive nature of the disposal sites in the Estuary, a key factor for understanding the fate of disposed dredged material is the resuspension and transport of deposited materials. At dispersive locations sediments are transported away from the disposal site during initial dispersion, and material that settles to the bottom is eroded and transported from the site by currents. As discussed in the Introduction, the major factors influencing sediment resuspension and transport are local water currents and the physical and chemical characteristics of the sedimentary deposits. Currents may be created by tides, freshwater inflow, and winds. Local areas of high turbulence may be created by wave action, propwash, and shoreline structures. After a brief review of the general circulation patterns in the Estuary, this section will describe the results of research on sediment erosion and transport.

In addition to the influence of tidal currents, wind-driven currents, and wind-derived turbulence as factors in sediment transport, river inflow generates gravitational circulation. In gravitational circulation, seaward-flowing surface currents of low-salinity water are found in conjunction with landward-flowing bottom currents of high salinity water. The landward-flowing bottom currents carry particles settling from the seaward-flowing surface currents back up the Estuary, where they become entrained in the freshwater flow, and are carried back toward the ocean. This forms a region of high suspended particle concentration. This region is referred to as the "null zone," or mixing zone, and is characterized by an accumulation of particles. Suspended particle concentrations of several hundred milligrams per liter can be found in this region, as compared to background concentrations in the Central Bay of 10 to 20 mg L^{-1} (Conomos *et al.*, 1979). Vertical mixing, which can be induced by high spring tides or high river discharge, weakens gravitational circulation.

Sediment transport in the Estuary is dynamic, with definite seasonal patterns. During the winter, when freshwater flow and sediment loads are high, and while winds are generally weak, sediments tend to be deposited in quiescent locations, such as the mudflats of Northern San Pablo Bay. In the summer, strong westerly winds resuspend these deposits and, in combination with tidal currents, transport suspended material throughout the Estuary. Changes in sediment depths can, thus, be dramatic and can occur over short periods of time. Krone (1976) described a channel cut to a proposed wharf in Carquinez Strait that shoaled 5 m (17 ft) in three months.

The ability of the tides to move suspended sediments is also significant, since the tidal excursion in the Estuary is approximately 10 km (Conomos, 1979). As slack water approaches, decreasing current velocities lead to the deposition of particles. As currents increase in velocity in the reverse direction, deposited sediments may be resuspended whenever the erosive force of the water exceeds the shear strength of the sediment deposit.

The complexity of sediment erosion and transport in the Estuary makes the determination of the fate of material at disposal sites a challenging task. It must be performed, however, in order to answer two key questions that relate to management of dredged material in the Estuary. These are 1) What are the quantities or proportions of dredged materials that are transported back to sites that must be dredged again, and 2) What is the extent of contaminant transport associated with eroded dredged material?

Investigation of dredged material fate and transport is a two-phase process. In the first phase, laboratory studies must be undertaken to understand the properties of sediments. In addition to basic soils engineering carried out in the laboratory, tracers can also be developed for field use. Laboratory data and valid tracer technology can then be used in the second phase, which comprises field studies of sediment erosion, transport, and deposition, and the use of field data to develop and verify numerical models.

The erosion of bottom sediments is difficult to measure, and estimates of erosion depend upon the methods used (Teeter, 1987). Erosion of a sediment exposed to increasing currents is a non-linear process that proceeds slowly until a critical threshold is reached, after which extensive erosion occurs. The composition of the material and the applied stress are the controlling factors, although consolidation of a deposit after deposition can also influence erodability (Parker, 1988). Trawle and Johnson (1986) calculated the potential for erosion and transport of dredged material deposited at the Alcatraz disposal site using various current regimes and dredged material characteristics. These calculations indicated that the existing currents close to the substrate at the site are sufficient to erode and transport both fine sand and unconsolidated clays and silts. The authors estimated that currents at the site could transport 40,000 yd^3 (30,000 m^3) of fine sand during an average tidal cycle. However, the erosion and transport of consolidated clumps of clay-silt is predicted to be much smaller, well below the rate at which such clumps may be deposited at the site from clamshell dredging operations. As a consequence, it was predicted that any significant dumping of consolidated materials from clamshell dredging operations would result in mounding at the site, and the natural consolidation and armoring of the mound over time would further increase resistance to erosion.

Laboratory experiments performed by Teeter (1987) provided empirical support for the calculations of Trawle and Johnson (1986). Three composite sediments (cored from the Alcatraz disposal site, Redwood Creek, and Larkspur/Richmond Longwharf) were exposed to known currents of saltwater in a laboratory flume. The critical shear stress for erosion (the applied shear stress at which erosion commences) depended on the bulk weight density of the sediment, and particularly the specific weight of fine

particles. Thus, increasing bulk densities resulted in decreasing erosion. Table 15 indicates that for dredged material with bulk densities greater than 1.5 g cm^{-3}, the currents at Alcatraz will not be sufficiently strong to result in significant erosion. Erosion would also be reduced by consolidation of sediments after deposition and the burial of more easily eroded material under more cohesive sediments.

To reduce mounding, the San Francisco District of the USCOE required dredged material to be disposed of at the Alcatraz site to be in a slurried form, as these materials should be (1) easily dispersed immediately after disposal, and (2) subject to greater erosion, should any material reach the substrate at the disposal site. In addition, the USCOE required that disposed materials be more evenly distributed throughout the Alcatraz site (BCDC, 1988a). The precise period of implementation of these requirements is disputed. USCOE (1988a) states that the slurring requirement did not actually take effect until Sepember 1987. The CDFG, however, states that correspondence from the USCOE indicates that operators of clamshell dredges were concerned about being able to implement a slurrying requirement in effect months before September 1987.

While these requirements may have slowed the rate of mounding at Alcatraz (SFBRWQCB, 1988), accumulation of disposed material is still occurring. The slurrying requirement has not proven very successful for clamshell dredging operations, which are the major source of consolidated sediments that are not easily eroded (USCOE, 1988a). Operators of clamshell dredges have had difficulties entraining sufficient water into consolidated dredged materials to produce a homogeneous slurry. The slurrying requirement has, therefore, recently been abandoned. Although it has been suggested that slower mounding could also be due to the recent disposal of mostly fine-grained material from maintenance dredging operations at the site, disposal data for 1986-1987 (USCOE, 1989a; 1989b) show that 25% of the disposed material (3.8 million yd^3, or 2.9 million m^3) originated from new work; 23% of this new work has been performed using clamshell dredges.

The USCOE developed a numerical model for examining sediment transport from the Carquinez disposal site in the mid-1970s (USCOE, 1976c). This model, known as *DREGSIM*, was only rudimentary in nature and employed a variety of simplifying assumptions, accounting for no particle resuspension or flocculation, no vertical variations in current velocity, and no ability for particles to leave or enter the modeling area. The model was not verified against measured concentrations of suspended solids. The more recent development of the *TABS-2* model by the USCOE has been discussed previously (see Section V.C.2.). *TABS-2* integrates hydrodynamic, disposal, and sediment transport elements. It is presently only in the developmental stage in relation to predicting the transport of disposed material throughout the Estuary, and has yet to be verified against actual data for suspended sediments collected in the field (Pankow, 1988).

The only large-scale tracer study yet performed in the San Francisco Estuary on matters related to the disposal of dredged material was undertaken in the mid-1970s by the USCOE to examine the fate of dredged materials disposed at the Carquinez site (USCOE, 1976c). In this study, the rare element iridium (Ir) was used as the tracer in a dredging operation that occurred from 19 February to 30 March 1974. Sediments

Table 15. Minimum currents required to erode sediments of different bulk weight densities and their frequency of occurrence at Alcatraz. After Teeter (1987).

Bulk Weight Density ($g\ cm^{-3}$)	Minimum current range needed for erosion ($cm\ sec^{-1}$)	Frequency (%) of these currents at Alcatraz
1.15	20-30	92.9
1.25	50-60	69.6
1.40	110-120	9.8
1.50	150-160	<0.1

taken from Mare Island Strait were labelled with Ir, and the labelled sediments were introduced into dredge hoppers (706 loads over 35 days) prior to release at the Carquinez disposal site. Samples of the top 23 cm (9 inches) of surface sediment were collected in Suisun and San Pablo Bays (a study area almost 260 km^2 in area) for 10 months, and were analyzed for Ir using neutron activation techniques.

The proportion of disposed material in each sample was determined by comparison of the concentration of Ir recovered in the sample to the concentration of Ir in the sediments released, corrections being made for background concentrations (3.16×10^{-10} g Ir g^{-1} dry wt. sediment). Some values of greater than 100% recovery were calculated, indicating the incomplete mixing of marked material within the hopper or the rehandling of previously marked material.

The study verified what one would expect for a dispersive site that shows no accumulation of disposed material over time. Shortly after disposal began, sediments contained relatively large percentages of disposed material at locations near the disposal site. However, by late March (six weeks after disposal of labelled sediments), smaller amounts of Ir-labelled material were present over a much larger area. In general, decreasing quantities of labelled dredged material in each sample were found in subsequent months, with some higher percentages appearing in the shallows of San Pablo and Suisun bays and in Mare Island Strait. The authors attributed the decreasing recovery of Ir-labelled sediments with time to either (1) the transport of material into Central Bay (or into wetlands and other areas not sampled), or (2) the burial of labelled material to a depth greater than that sampled. A special analysis at one site indicated the presence of Ir-labelled sediments to depths as great as 74 cm (29 inches).

By October 1974, labelled dredged sediments began to reappear in small quantities throughout much of the study area. This may have been due to reductions in wind speed and changes in wind direction, resulting not only in the movement of labelled sediments out of the shallows and back to the sampled area, but also the new deposition of small particles previously maintained in suspension by stronger winds. The semi-annual dredging of Mare Island Strait also recommenced at this time, and Ir-labelled dredged material from the previous spring that had been transported to and deposited in the channel was re-dredged and once again introduced at the Carquinez disposal site. By December 1974, the amount of labelled material in sediment samples from the study area had again decreased significantly.

The movement of dredged material out of the study area was verified by sampling in Central and South bays. Sampling of sediments in September at the Richmond Bridge (4.38% dredged material), Alameda (3.52%), and Emeryville (2.41%) showed that Ir-labelled dredged material introduced at the Carquinez disposal site was being transported to these locations. Smaller concentrations were detected in Richmond Harbor, Berkeley Pier, Oakland Outer Harbor, off San Francisco airport, and at Islais Creek.

These tracer studies support the concept that the Carquinez disposal site acts as a *bona fide* dispersal site for dredged sediments. The labelled sediments were transported over a wide area and appeared to enter the overall sediment cycle in the

Bay, being resuspended and redeposited according to changes in wind conditions. Some of the labelled material was clearly deposited in the original area of dredging. USCOE (1976c) concluded that approximately 10% of the disposed material returned immediately to the Mare Island Strait. This value agrees with an earlier study in which 5-15% of sediments labelled with radioactive gold (^{198}Au) and released at the Carquinez site on a flood tide were recovered in the Strait (Krone, 1960 in USCOE, 1976c). It should be noted, however, that this estimate was based not upon a budget for the labelled material, but on the relative concentrations of iridium present in the labelled sediments disposed and in the sediments sampled later. It is clear from these data that labelled sediments indeed returned to the Strait (and were later redredged), and that new sediments were also deposited in the Strait; new sediments were deposited at a rate about nine times that of the labelled sediments. However, in the absence of a complete budget for the labelled material, it is not possible to calculate the amount of labelled material (and thus dredged material) that was redeposited in the original area of dredging.

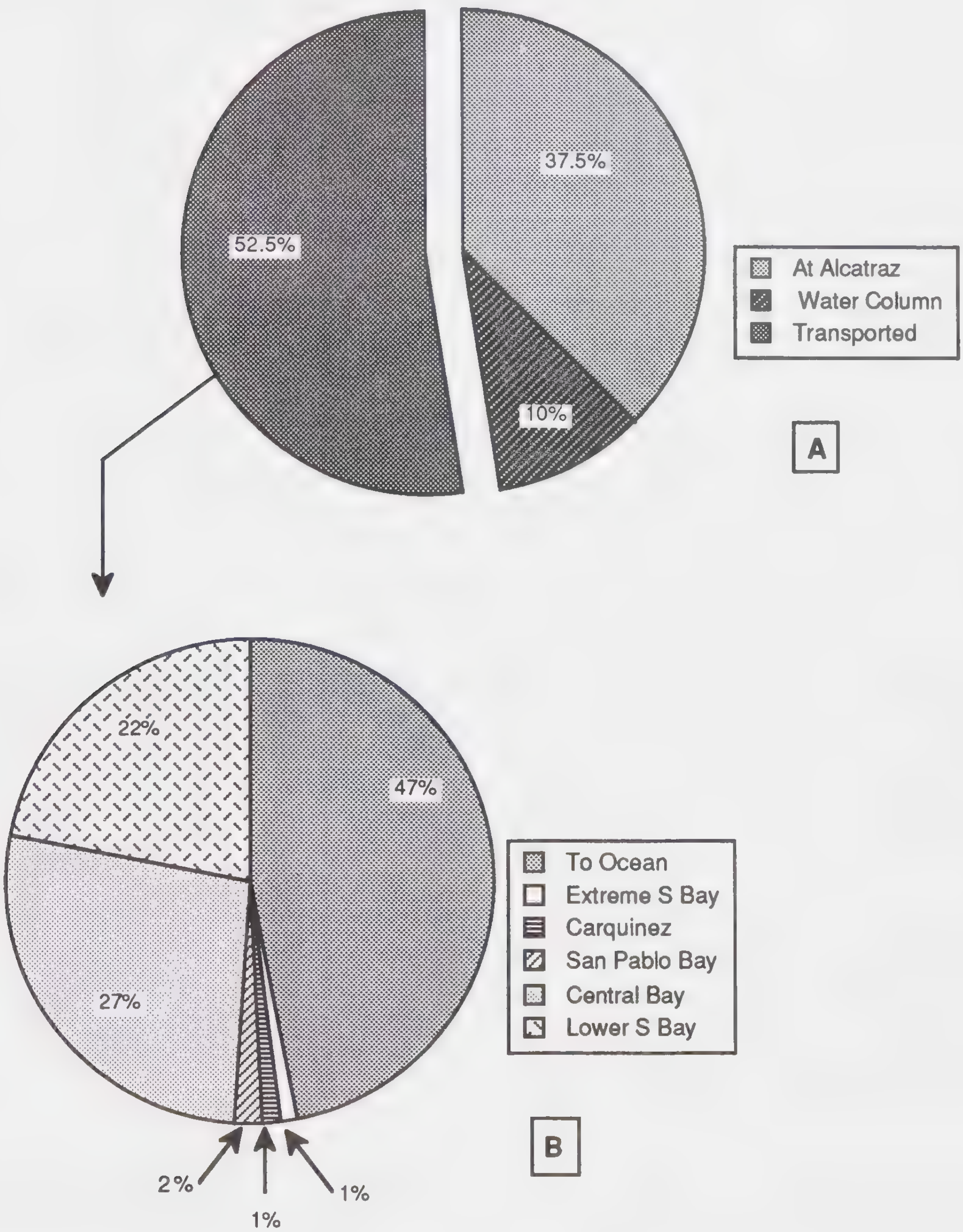
No tracer studies have been performed on material disposed at the Alcatraz site. As the Alcatraz disposal site receives the majority of the dredge spoils disposed of to the Bay, implementation of tracer studies at the Alcatraz site should have high priority. New techniques using bacterial viruses (bacteriophages) make tracer studies more economical and more sensitive. When the USCOE performed the tracing study using Ir in 1974, the requirements of the study necessitated that they purchase a major portion of the refined global supply of this rare element (R. Engler, USCOE, personal communication).

5. Sediment Budget for the Alcatraz Disposal Site

USCOE (1988a) recently presented a budget for material disposed at the Alcatraz site. This budget is derived from the results of studies using the Bay Model and unpublished bathymetric surveys and disposal logs. From these data USCOE (1988a) concluded that 52.5% of the material deposited at Alcatraz was transported away from the site, 37.5% remained at the site, and 10% was suspended in the water column during convective descent of the material (Fig. 26a). The value of 37.5% for material remaining at the Alcatraz site is close to the range of estimates presented above from modeling studies and bathymetric observations (Trawle and Johnson, 1986; SAIC, 1987a). Clearly, these percentages will vary significantly depending upon the characteristics of the dredged material, particularly the bulk weight density. Figure 26 shows the fate of the material transported from the site according to USCOE (1988a). It was estimated that 47% of this material (or 25% of the material initially disposed at the site) was transported through the Golden Gate to the ocean, while 53% (or 28% of the material disposed) was transported landward and deposited in various portions of the Bay, with deposition in Central Bay and lower South Bay predominating.

The estimates for the fate of material transported from Alcatraz were made using the San Francisco Bay Physical Model (Homan and Schultz, 1963; USCOE, 1965; USCOE, 1967). In these tests, finely ground gilsonite (a naturally occurring asphaltic material) was mixed with water (9:1 gilsonite:water) and injected at various points in the Bay Model to simulate the disposal of dredged material. The model was then run

Fig. 26. The fate of dredged material disposed of at the Alcatraz disposal site. A: Fate of all disposed material. B: Fate of material transported away from the site. Data from USCOE (1967).



over several tidal cycles, and the distribution of the gilsonite was determined. The results of these tests are summarized in Table 16. A significant fraction of the released material was predicted to be retained in the Estuary, with the percentage retained being inversely related to the distance of the disposal site from the Golden Gate.

There are several limitations to these studies with the physical model. As discussed by USCOE (1967), the Bay Model does not reproduce currents due to the action of wind and waves; hence, the impacts of such currents on sediment resuspension and redeposition in the Estuary are not included in the gilsonite studies. Although non-tidal currents are normally only about one tenth the strength of tidal currents (Conomos, 1979), they are thought to nevertheless be important in determining the ultimate fate of dredged material disposed in the Estuary (especially where material is deposited in shallow areas). Consequently, USCOE (1967) states that the results of its studies (Fig. 26; Table 16) represent the *initial* distribution of sediments transported away from the Alcatraz disposal site, rather than the *ultimate* sites of deposition for this material. Such limitations influence the degree of confidence that can be placed in the gilsonite studies.

USCOE (1967) also points out that the experiments with the Bay Model do not *quantitatively* reproduce shoaling in the Estuary. This is because it is necessary to inject quantities of gilsonite much greater than the actual scaled volume (1:100,000,000) of dredged material in order to recover gilsonite from different parts of the model in quantities that can be accurately measured. In addition, these injections of gilsonite occur over relatively short periods. For example, in one study, 100,000 cm^3 of gilsonite was injected in 75 min. Scaling-up from the model shows that this is equivalent to dumping 13,100,000 yd^3 (10 million m^3) of dredged material in 5.2 days. This is clearly unrealistic as a model for disposal in the Estuary (USCOE, 1965).

However, the use of gilsonite injections may reproduce the *relative* rates of shoaling in different portions of the Estuary reasonably accurately (USCOE, 1967). This conclusion is based upon comparisons of relative shoaling rates observed in the field at sites such as the Alameda Naval Air Station channel with predictions of shoaling rates from experiments using gilsonite injections into the Bay Model. As this verification is only on a local scale, gilsonite experiments for the whole system must be interpreted with caution.

Some of the limitations of the physical model study were not discussed by USCOE (1988a). In addition to the limitations due to volumetric scaling and non-tidal currents, there exist limitations having to do with the fact that 1) the transport of gilsonite does not appear to model accurately that of suspended sediment in the Estuary and 2) the physical model does not model the vertical current profile of the Estuary in the vicinity of the Golden Gate.

As for the transport problem, gilsonite tends to sink and be carried along the substrate of the model; it is also only weakly resuspended. This problem is further exacerbated by the need to include roughness elements along the floor of the model to obtain the appropriate level of friction between the substrate and the overlying water column. These elements (which are small copper strips) are necessary for hydrodynamic modeling, but, according to USCOE (1967), cause localized turbulence

Table 16. The distribution of disposed dredged material, as simulated using gilsonite in the Bay Model. Data from USCOE (1967).

Disposal Site	% gilsonite retained in Bay
Golden Gate	35
Alcatraz	53
Hunters Point	90
Yerba Buena	71
Angel Island	73
Pinole Shoal	95

which alter the flow and deposition of gilsonite particles. This limits the ability of the physical model to simulate the movement of suspended particles on a local scale, although the presence of the roughness elements should improve the overall performance of the physical model in simulating sediment movements by modeling vertical currents that contribute to particle suspension and transport (W. McAnally, USCOE, personal communication).

As for the problem of vertical current profile, the available data on long-term current measurements performed in this region clearly show a net landward flow of water at depths greater than approximately 15 m (Conomos, 1979; SAIC, 1987b, 1987c; Smith, 1987). Thus, net currents in a seaward direction are observed in these deeper waters only during periods of unusually high Delta outflow. This net landward flow of deeper water at the Golden Gate has critical implications for the transport of suspended sediments from disposal operations at Alcatraz, as a major portion of the initially dispersed sediments and any material eroded from the substrate will be entrained in the lower water column. As the time-averaged transport of suspended sediments is greatly influenced by net water movements, the authors speculate that most of the suspended sediments from dredged material disposed at Alcatraz is transported to the Estuary rather than being transported through the Golden Gate to offshore ocean waters.

The landward transport of suspended sediment in the region of the Golden Gate has been demonstrated by seabed drifter studies (Conomos *et al*., 1970). In this early study, seabed drifters were released within the Estuary, at the Golden Gate, and in the Gulf of the Farallones. After six weeks, 18% of the 1,345 drifters were recovered, and 81% of those were found within the Estuary. During 1970-73, 18 such drifter experiments were conducted, and only a few of the thousands of seabed drifters released at the Golden Gate or landward of this location were recovered in offshore waters west of the Gate. By contrast, none of the thousands of surface drifters released at the same points were found landward of the Golden Gate (Conomos and Peterson, 1977). This strongly suggests that, in the Central Bay, only those suspended sediments found in the upper water column will be transported to the ocean. On the basis of these data, Conomos and Peterson (1977) questioned the analysis of USCOE (1965) and USCOE (1967) (Table 16). Conomos and Peterson (1977) concluded that little if any sediment is transported seaward close to the substrate of the Estuary in the region of Alcatraz and the Golden Gate. They cite the estimate of USCOE (1965) that 30% of the annual riverborne load of sediments is transported to the sea, and suggest that this should be only 6%.

Since 82% of the seabed drifters released by Conomos *et al.* (1970) were never recovered, there is still uncertainty with regard to the extent of landward transport of suspended sediments. It could be argued that drifters transported seaward are less likely to be recovered, introducing bias into the experiment. In addition, the lack of precise correlations between the movement of bottom sediments and seabed drifters requires that conclusions from drifter studies be of a qualitative nature only (Clausner, 1988). The overwhelming percentage of seabed drifters recovered landward, however, combined with the data on long-term currents, argue strongly for the net landward transport of suspended sediments in the deeper waters of Central Bay.

It is therefore clear that the sediment budget for the Alcatraz dump site presented by USCOE (1988a) is of uncertain accuracy. It appears that the ultimate fate of the material transported from the Alcatraz disposal site cannot be determined from the work of USCOE (1967), as this study does not account for the non-tidal circulation of sediments. Given the vertical current profiles in the region of Alcatraz and the Golden Gate, it appears unlikely that 47% of the sediment transported from Alcatraz would be carried to the ocean. To better understand the fate of dredged material disposed at Alcatraz, improvements in numerical and physical models and additional field experiments are necessary. Perhaps the most critical field experiment would be a tracer study to examine the fate of suspended solids released at that site, possibly employing bacteriophages as tracers. This technique offers considerable advantages over the more traditional methods employing chemical tracers, including a greatly enhanced sensitivity (Drury and Wheeler, 1982).

Recent studies (USCOE, 1987a) indicate that differences in surface and bottom currents do exist in Bay Model simulations, with landward near-bottom residual currents being measured for most hydraulic conditions in the vicinity of the Alcatraz disposal site. To obtain accurate measurements of bottom currents, the copper strips used to simulate surface roughness were removed. As several recent modifications have been made to the Bay Model, and more are planned in the near future, the tidal currents generated by the model must be verified against data from the Estuary to determine the accuracy of simulations conducted with the model (T. Wakeman, USCOE, personal communication). If the model does not accurately reflect the net landward circulation of deeper water at the Golden Gate, it will not be possible to use results from the model to predict the initial transport of suspended sediments from disposed dredged material at Alcatraz. In that event, the revision of existing numerical models to reflect the stratification of currents in this critical region of the Estuary is particularly important. W. McAnally (USCOE, personal communication) indicates that physical models are commonly able to reproduce vertically stratified currents accurately).

Segar (1988) has recently speculated that a large portion of the sediments suspended during disposal operations at Alcatraz and eroded from the mound at this site remain in the western portion of San Francisco Bay, accumulating in quiescent regions along the San Francisco and Marin County shorelines. He proposed that the concentrations of toxic contaminants in the sediments of Richardson and Elliot bays could be due to the deposition of disposed material, as these areas have limited local sources of such contaminants. However, the seabed drifter studies cited above (Conomos *et al.*, 1970; Conomos and Peterson, 1977) suggest that suspended material in the deeper waters of Central Bay will be transported into the northern reach of the Estuary. Segar (1988) indicates that the lack of extensive field data does not permit the fate of material disposed at the Alcatraz site to be accurately determined; this conclusion is supported here.

6. Transport of Disposed Material Back to Dredging Sites

A critical question related to the ultimate fate of dredged materials in the San Francisco Estuary is the extent to which material presently disposed of at sites within the Bay is transported back into navigation channels, from which it must be re-

dredged. Any such redeposition of previously-dredged materials in areas requiring ongoing or future ("new work") dredging may add to the overall costs of maintaining navigable channels in the Estuary, and may erode some of the cost differential between within-Bay disposal and other disposal options.

USCOE (1965) examined the return of disposed dredge materials to navigation channels with the use of a crude sediment budget for the Estuary. The calculation assumes 10 million yd^3 (7.6 million m^3) of new sediments are delivered to the Bay each year, and 3 million yd^3 (about 2.3 million m^3) of this new material is transported out of the Bay, to offshore oceanic waters. Using an estimate of annual average net deposition in the Estuary in areas outside those requiring maintenance dredging of 3.4 million yd^3 (2.6 million m^3; based upon sediment surveys), and assuming that all of this is new material, it follows that 6.4 million yd^3 (4.9 million m^3) of the new material will not generate a requirement for annual dredging. The difference between the amount of new material entering the Estuary annually and this amount which does not generate a requirement for dredging (10.0 million yd^3 minus 6.4 million yd^3, equals 3.6 million yd^3) is equivalent to the amount of new material which is deposited in the navigation channels annually. USCOE (1965) estimated total dredging in the Estuary at 11 million yd^3 (8.4 million m^3) annually, implying that 7,400,000 yd^3 (5.7 million m^3; equivalent to 67% of material dredged each year) was in fact dredged material from earlier disposal operations.

The procedure of USCOE (1965) assumed that shoaling of navigation channels is due only to deposition of new sediment, or previously dredged sediment. It did not account for shoaling due to resuspension and transport of sediments already in the Estuary. This was an important oversimplification. It has been estimated by Krone (1966, 1974) that over 100 million yd^3 (76 million m^3) of sediments are resuspended annually. A significant fraction of the deposition assumed by USCOE (1965) to be previously dredged sediment was undoubtedly resuspended material. Thus, the percentage of material reworked was certainly overestimated. The percentages were probably also inaccurate due to the consideration of total dredging rather than maintenance dredging, as new work projects are much less likely to include reworked material.

These crude calculations do suggest that a portion of the material dredged each year in the Estuary is reworked material. The results of tracer studies also show that sediments from Mare Island Strait include material recirculated from the Carquinez disposal site. Additional tracer studies are needed to determine the amount of reworking and recirculation that occurs during dredging operations in the Estuary.

7. Summary of the Fate of Dredged Material

The sediments of the Bay/Delta are extremely dynamic, with erosion or deposition of material constantly occurring in response to complex patterns of currents and waves created by river flows, tides, and winds. The aquatic disposal of dredged sediment thus adds suspended material to a constantly changing environment, and determining the ultimate fate of disposed dredged material is a challenging task.

The ultimate fate of dredged material is relevant to three key management questions. These questions involve: (1) the extent and precise cause of accumulation at the Alcatraz disposal site; (2) the amount of disposed material that returns to navigation channels and must be re-dredged; and (3) the distribution and fate of contaminants associated with dredged material. Laboratory and field studies indicate that the disposal of consolidated dredged material, particularly high-density sediments from clamshell dredging operations, is the major cause of mounding at Alcatraz. Few field data are available on the early stages of mound formation, making it impossible to verify the dynamics of this process. The initial development of the mound probably accelerated further accumulation by reducing the distance disposed material could travel through the water column prior to striking the substrate. Illegal disposal of construction material at the site might also have contributed to mound formation.

The ultimate fate of dredged material disposed at aquatic sites in the Estuary is unknown. The initial dispersion and transport of disposed material has been investigated using numerical and physical models. While these models provide a basis for describing the Estuary, they are currently in the process of revision and verification. Depending upon the success of these efforts, the models could be an important source of information upon which management decisions could be based. The revision and verification efforts should address the modeling of vertically-averaged current regimes; inadequate data on the physical characteristics of disposed material that influence transport processes; and the capability to recreate the wind-driven currents so vital for understanding the long-term transport of suspended materials in the Estuary. Sensitivity analyses should also be undertaken, and efforts should be made to develop estimates of the absolute error in model predictions. Until the processes of revision and verification are complete, conclusions about the ultimate fate of disposed dredged material based upon these tools should be viewed with some skepticism.

Given the complexity of modeling sediment transport, the use of tracer studies to elucidate the fate of disposed material could be most beneficial. The only tracer experiment that has been performed on disposed dredged material in the Estuary was conducted 15 yr ago at the Carquinez disposal site. This study documented the transport of disposed material over considerable distances in the Estuary and demonstrated the apparent role of winds in moving sediments from shallow regions. It also demonstrated that material disposed at aquatic sites will return to navigation channels, requiring re-dredging at a later time. New highly sensitive and economical tracing techniques could be used in the Estuary to gain a better understanding of the fate of material disposed at aquatic sites.

D. EFFECTS OF DREDGED MATERIAL DISPOSAL

Dredged material disposal may affect the ecosystem of the San Francisco Estuary in several ways. Deposited dredged material may impose direct, physical effects upon the benthos (burial or smothering; Sherk, 1971; Morton, 1976), or it may cause indirect effects upon the benthos by altering the particle size-distribution or chemical composition of the substrate (Morton, 1976; Boesch, 1982). Deposited dredged material may also serve as a source of contamination to the benthos, possibly leading to acute or chronic effects and/or to the transport of contaminants into and through the food chain (O'Connor *et al.,* 1982; Rubinstein *et al.,* 1983, 1984; Gentile *et al.,* 1988).

Dredged material that becomes suspended during dredging or after disposal may also affect the ecosystem, but in ways that are somewhat different than the effects of deposited material. Suspended material in high concentrations may affect benthic, pelagic, and planktonic animals directly by affecting respiratory surfaces (Rogers, 1969; O'Connor *et al.,* 1976). While such effects are generally not lethal (Morton, 1976; O'Connor *et al.,* 1976), sublethal effects, such as increased energy expenditure, decreased oxygen exchange capacity of the gills, and altered hematological parameters may be caused by prolonged exposure to high concentrations of suspended material (O'Connor *et al.,* 1977; Neumann *et al.,* 1982). Among primary producers, suspended dredged material may reduce light penetration in the water column causing a reduction in carbon fixation in the Estuary (Sherk *et al.,* 1977).

Most important, perhaps, is the fact that contaminated dredged material may serve as a source of contaminants that had previously been sequestered in sedimentary deposits. Potentially harmful materials that had been taken "out of circulation" by natural processes may, once again, become distributed among benthic and pelagic communities over an area substantially greater than a designated disposal site (O'Connor *et al.,* 1982; Lake *et al.,* 1985; Gentile *et al.,* 1988), where the possibility of accumulation, toxicity, and food-chain transport becomes substantial (O'Connor and O'Connor, 1983; Gentile *et al.,* 1988).

This section reviews the potential effects of dredged material disposal on estuarine biota. The topics examined include 1) sediments as sources and sinks for contaminants, 2) the bioavailability of contaminants in dredged material, 3) the potential acute and chronic effects of major contaminants in dredged materials, and 4) the potential effects of turbidity on biota. This section focuses on the effects of dredged material disposal in the Bay, due largely to a lack (at the time of preparation of this report) of local data on the effects of disposal in upland or aquatic environments in the Delta. Recent developments have greatly increased the likelihood that disposal in the Delta will become an important alternative for disposal of sediment dredged both from the Bay and the Delta. The effects of disposal in the Delta should be carefully considered as this practice becomes more common.

1. Sediments as Sinks and Sources for Contaminants

Sediments are a sink for contaminants in estuaries, and the San Francisco Estuary is no exception (see Section V.B.). Contaminants exist in sediments in several

forms, not all of which have equal potential to affect the biota. Factors that influence mobilization of contaminants in dredging and disposal operations include the physical characteristics of the sediments and the individual contaminants, the characteristics of the disposal site, and the dredging equipment used.

A. PHYSICS AND CHEMISTRY OF DREDGED MATERIAL CONTAMINATION

1. Metals

A technique called "bulk chemical analysis" is used to assess contaminant concentrations in sediment. Bulk chemical analysis provides an indication of the total contaminant concentrations in sediments, but a knowledge of the physico-chemical states of the contaminants is also necessary to understand the manner in which contaminant release may occur during dredging and disposal.

The physico-chemical state of trace elements in sediments is more complex than that of organic compounds. A portion of the total trace elements present is found tightly bound in the crystalline structure of minerals in sediments, where the metals have been substituted during crystal formation for more common mineral components such as aluminum, magnesium, or silicon. Such contaminants can only be released by destruction of the mineral. Trace elements can also be found between crystalline layers in clay minerals such as montmorillonite, which is the predominant clay mineral in the Bay and Delta (Serne and Mercer, 1975). Although more easily mobilized than lattice-bound atoms, trace elements in inter-layer positions are still relatively unavailable for exchange or remobilization.

Anoxic sediments (those containing no oxygen) occur as the result of bacterial metabolism of organic matter in sedimentary deposits. Trace elements in moderately anoxic sediments may exist in forms that are more readily mobilized than lattice-bound or inter-layer metals. Under anoxic conditions, micro-organisms can utilize electron acceptors other than oxygen, such as nitrate (reduced to ammonia), sulfate (reduced to sulfide), ferric iron (reduced to ferrous iron), and various organic compounds. Thus, anoxic sediments may contain a variety of chemical compounds not found in aerobic environments. Of particular interest are sulfides, which are often formed with various trace elements. Sulfide-metal complexes generally remain as insoluble forms in reduced sediments. Other precipitates in sediments include carbonates and a variety of organo-metallic complexes (Gambrell *et al.*, 1976). Under extremely anoxic conditions trace elements may be highly immobile (F. Reilly, USCOE, personal communication).

Trace elements may also be bound in sediments by ionic interactions involving negatively charged surfaces of minerals, fulvic and humic acids and positively charged cations including trace metals. Substances in this form, often termed "exchangeable cations," are easily mobilized. particularly under acidic conditions.

Finally, contaminants can be dissolved in interstitial waters ("pore waters") of sediments. The proportion of contaminants in this fraction is generally small, but these contaminants are easily mobilized by disposal or by consolidation of disposed dredged material in a mound (Dayal *et al.*, 1981) and may become available to biota

in the water column. On the other hand, trace elements in pore waters are also the most likely fraction to precipitate out of solution as oxides and hydroxides of iron and manganese as sediment is exposed to oxidizing conditions during the dredging process. Contaminants in pore waters exist as free ions and in various organic and inorganic complexes, and their concentration often is independent of the total contaminant levels in sediments (Burks and Engler, 1978).

The physico-chemical states of trace metals in sediments can be determined using the technique of sequential leaching and analysis. The extent to which a sediment may act as a source of metals to biota may be inferred from the strength of binding of metallic ions to the sediment (i.e., the strength of the reactions needed to extract the metal in question; Burks and Engler, 1978).

Simple filtration and centrifugation may be used to isolate pore waters for metals analysis. Pore water analysis demonstrates which metals are immediately available to the biota. Weak oxidants are employed to leach metals from the surface adsorption sites on sediment particles and show which metals may become bioavailable by simple leaching in surface waters. Digestion under strong oxidizing conditions is necessary to determine the amount of lattice-bound trace metals and identifies those metals that are unlikely to be released from sedimentary material under any natural conditions. However, accepted standard methods are not available for any of these techniques, and different investigators have utilized different procedures (e.g., see Serne and Mercer, 1975; Burks and Engler, 1978).

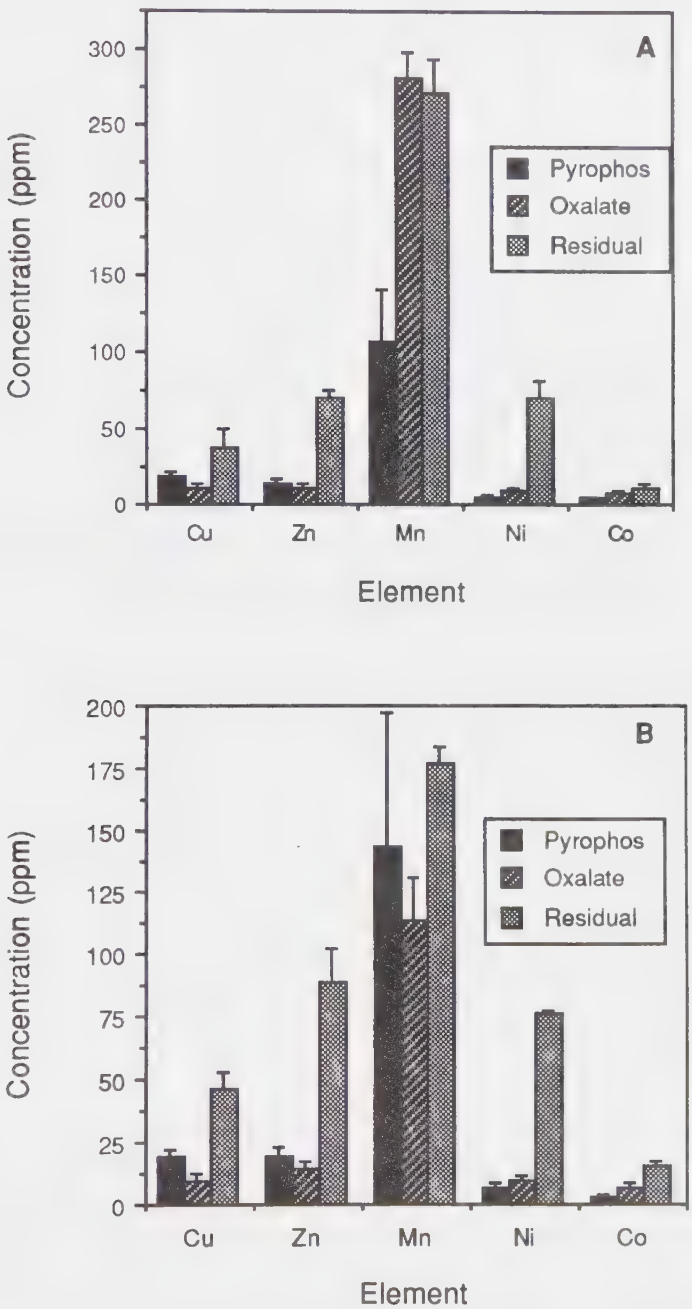
Certain extraction techniques may elute metals from more than one site (Gambrell *et al.,* 1976), and it is also possible that one phase will adsorb metals released from another prior to measurement (Serne and Mercer, 1975). Some investigators have employed techniques that oxidize or physically alter sediments, making the interpretation of results difficult. Research has demonstrated that sediments with similar bulk chemistry may contain trace elements in different physico-chemical states, and site-specific data are thus necessary before any conclusions may be reached regarding the relative availability of metals from different sediments (Brannon *et al.*, 1976).

Two studies have examined the physical chemistry and the availability of metals from sediments in the San Francisco Estuary (Serne and Mercer, 1975; Eaton, 1979). Eaton collected samples of surface (top 5 cm) and sub-surface (below 5 cm) sediment from the "North Bay" (Carquinez Strait and Suisun Bay), San Pablo Bay, Central Bay (including the Gulf of the Farallones), and South Bay. Copper, zinc, manganese, nickel, and cobalt were measured as:

(i) organically bound metals, as determined by a 24-hour leach in pyrophosphate solution at pH 10;
(ii) metals bound to iron oxides, as determined by leaching the remaining solid for 4 hr in ammonium oxalate/oxalic acid at pH 3.3; and
(iii) residual metals, as determined by digestion of the remaining solid in strong acid.

Some of these data are presented in Fig. 27. Except for manganese, the metals studied were mostly in the residual phase; that is, they were relatively unavailable to

Fig. 27. Trace metal fractions in San Francisco Bay sediments using sequential leaching techniques. Fractions depicted for subsurface (below 5 cm) sediments are; organically-bound metals (Pyrophos), metals bound to iron oxides (Oxalate), and metals in crystalline matrix (Residual). A: Carquinez Strait/Suisun Bay sediments; B: San Pablo Bay sediments. Data from Eaton (1979).



biota. As shown in Fig. 28, the percentage of total metals present in the residual phase in all four regions tested was at least 40% and usually higher, particularly for zinc (greater than 70%) and nickel (greater than 80%). Although it would appear that a significant quantity of metals was organically bound, Eaton (1979) points out his procedures were not carried out under oxygen-free conditions; the oxidation of sulfides may have contributed to the metals released in this fraction.

Serne and Mercer (1975) sampled sediments from ten stations in various dredging projects around the Estuary, including Mare Island Strait, Richmond Harbor, and Oakland Harbor. The extraction procedure examined six fractions, as follows:

(i) interstitial water (under an inert atmosphere);
(ii) exchangeable metals, using ammonium acetate (under an inert atmosphere);
(iii) oxides and carbonates using hydroxylamine hydrochloride at pH 2 (under an inert atmosphere);
(iv) organics and sulfides using hydrogen peroxide;
(v) iron oxides using sodium citrate and sodium dithionite; and
(vi) residual metals using strong acids.

High percentages of the metals in the sediments studied were released in fractions (iv) and (vi). Figure 29 shows the percentage of metals in these fractions for the three stations for which this analysis was made. These data show that the physico-chemical distribution of metals within the sediments studied was consistent among stations, with the exception of cadmium, the majority of metals were in the residual phase (Fig. 29b). Ninety percent of the Cd was leached by hydrogen peroxide (Fig. 29a). Serne and Mercer (1975) and Eaton (1979) found similar distributions of zinc and copper between these two fractions.

It is important to note that the assignment of metals to particular forms by these techniques is purely empirical. Methods are not yet available to examine the *in situ* chemical forms of trace metals in sediments, and it is not possible to verify that the various fractions extracted by different chemical treatments actually represent a particular form or availability to biota (Brannon *et al.*, 1976). Moreover, studies using different leaching techniques cannot be accurately compared. Although Eaton (1979) and Serne and Mercer (1975) show limited variation among fractions, other studies have shown that the physico-chemical distribution of metals in sediments varies considerably among sites (e.g., see Kester *et al.*, 1983). Thus, the similarity indicated by the two studies in the San Francisco Estuary may be fortuitous.

2. Organic Contaminants

The organic contaminants associated with sediments and dredged material generally comprise those that are sparingly soluble in water and which have a strong tendency to sorb to surfaces of fine particles. This includes higher molecular weight compounds with low vapor pressures and high lipid solubility (Freed and Chiou, 1981). Organic contaminants of concern in most studies of dredging and dredged material disposal include the PCBs, DDT and its metabolites, the cyclodiene class of chlorinated pesticides (e.g., dieldrin, chlordane, endosulfan), and higher molecular weight polycyclic aromatic hydrocarbons (PAHs; benzo[a]pyrene, benz[a]anthracene)

Fig. 28. Percentages of trace metals found in the residual fraction in San Francisco Bay sediments Data are for subsurface (below 5 cm) sediment samples, from Eaton (1979).

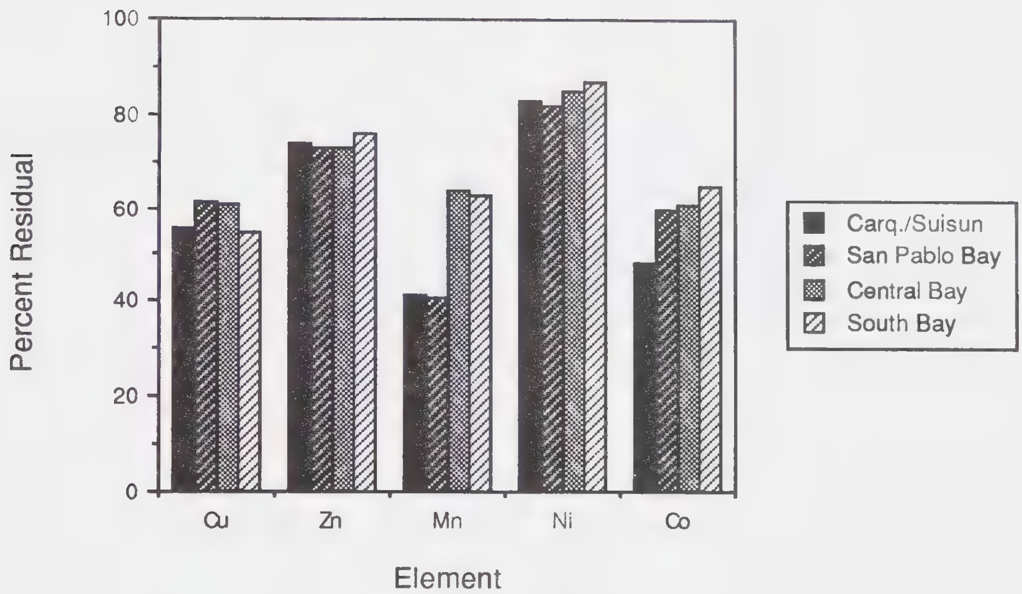
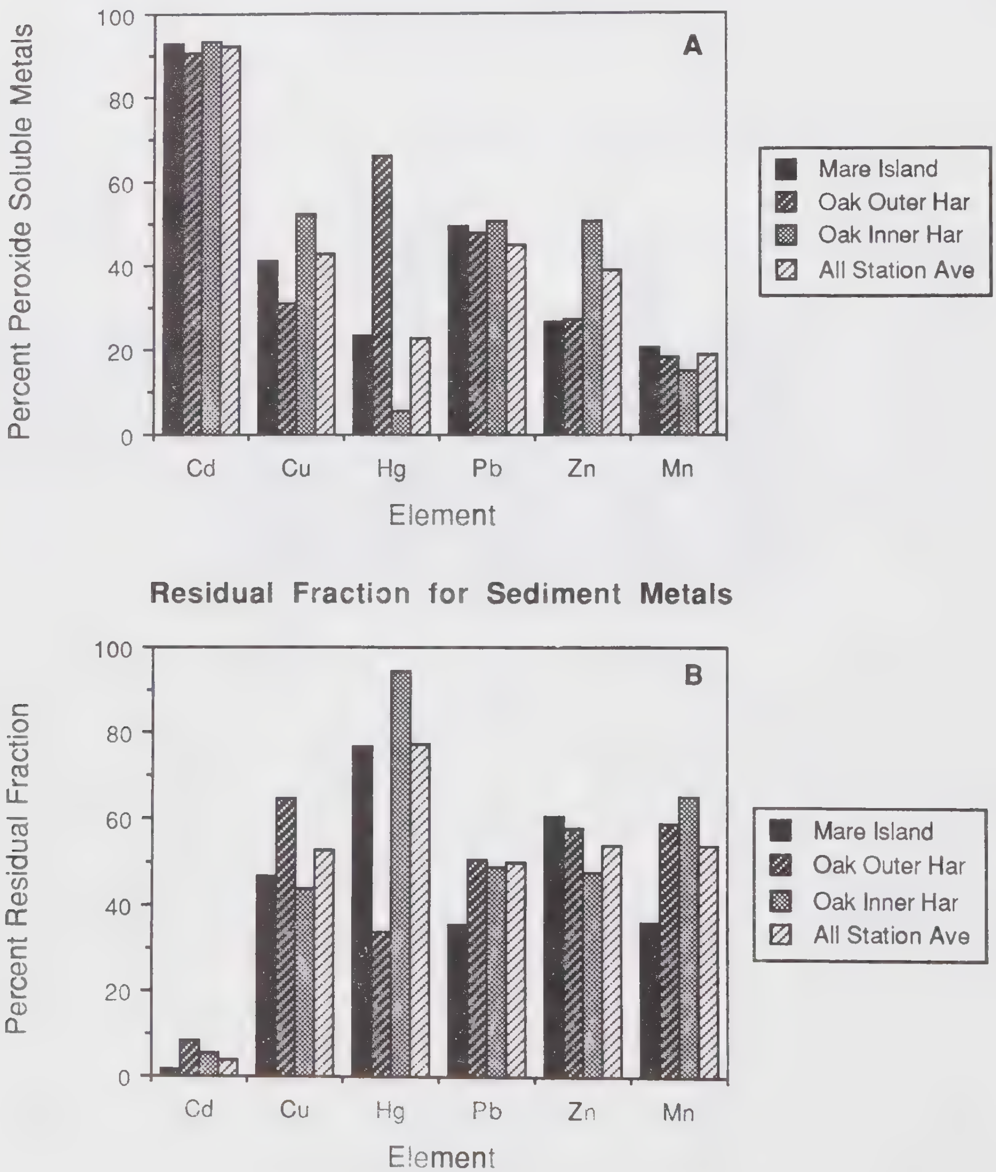


Fig. 29. Percentages of trace elements found in the hydrogen peroxide (A) and residual (B) fractions. Data refer to surface 30 cm of sediments. Data from Serne and Mercer (1975).



(OTA, 1987). Other classes of compounds (low molecular weight chlorinated hydrocarbons, monocyclic aromatic compounds, carbamates, organophosphates) occur in sedimentary deposits (e.g., MacLeod *et al.,* 1981; Bieri *et al.,* 1982), however, environmental fate for these compounds is dissolution in the water column, biodegradation and/or and volatilization to the atmosphere (O'Connor and Kneip, 1986; OTA, 1987). The fate pathway for the soluble classes of organic contaminants rarely includes bioconcentration or bioaccumulation (O'Connor and Kneip, 1986; OTA, 1987).

The nature and behavior of synthetic organic compounds in sediments is relatively poorly understood. These contaminants do not become bound in mineral lattices, occupy interlayer positions in clays, or form sulfides or other insoluble compounds. They are not generally found as part of the exchangeable fraction; rather, they are associated with finely divided particles (Karickhoff *et al.,* 1979) and dissolved and particulate organic carbon in sediments (Adams, 1987). They are bound with particles, colloids, and various organic molecules through the action of van der Waals forces and preferential partitioning among different chemical phases of water, sediments, and organic matter (Brownawell, 1986; Podoll and Mabey, 1987).

Surface adsorption may appear to be similar to the cation exchange capacity for metals on the surface of particles. This is not the case. Whereas cation exchange may occur due to slight changes in ionic strength of the medium surrounding particulate matter, surface adsorption of organic material with sediments is a phase-exchange phenomenon determined by the chemical affinity of the organic molecule for a particular chemical phase (Karickhoff *et al.,* 1979; Hutzinger, 1981; Karickhoff and Morris, 1984).

B. PHYSICO-CHEMICAL PROCESSES AFFECTING CONTAMINANT REMOBILIZATION

This Section discusses the physico-chemical factors influencing the release of contaminants from sediments. Data from laboratory and field studies on the consequences of such releases of contaminants for their uptake by organisms are reviewed in Section V.D.2., below.

1. Metals

The oxidation/reduction, or "redox" potential (expressed as Eh) of sediments is one of the most important factors influencing the mobilization of contaminants, especially trace metals. Anoxic sediments are characterized by an Eh of -100mV or less; oxygenated waters, in contrast, exhibit Eh values >400mV (Kester *et al.*, 1983). When an anoxic sediment is placed into oxygenated waters, a significant increase in Eh may occur, and this may change the physico-chemical state of trace metals bound to sediments and, hence, alter their availability. Hydraulic dredging, in which sediment and water are mixed prior to disposal, can also increase the Eh of dredged material.

The response to changes in redox potential varies for different trace metals. In general, increasing Eh results in the oxidation of metal sulfides, rendering most trace metals more soluble. However, manganese and iron precipitate as amorphous

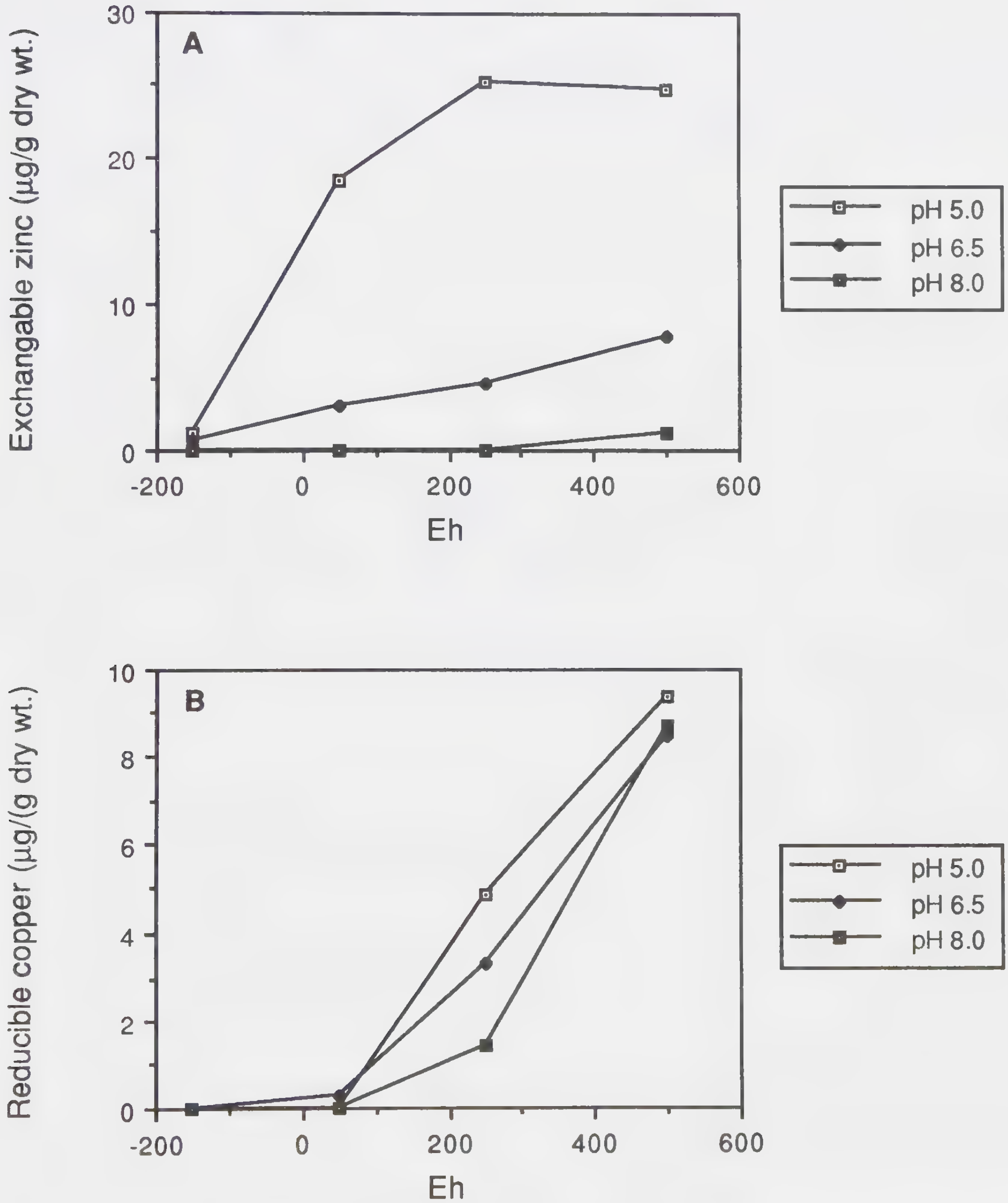
hydroxides and can "scavenge" soluble trace metals from the water column through co-precipitation (Gambrell *et al.*, 1976; Burks and Engler, 1978). Organically bound metals may become more available in aerobic environments as complex humic material is degraded. As the oxidation of organic matter and sulfides is a slower process than the precipitation of amorphous hydroxides, the length of time dredged materials are exposed to oxidizing conditions is critical to the final concentrations of metals released.

Serne and Mercer (1975) also demonstrated the importance of redox conditions on the release of trace metals from sediments in the laboratory. Using elutriate tests in which Eh was controlled, significantly higher concentrations of copper, cadmium, lead, and zinc were released under oxidizing conditions than under reducing conditions. These authors also demonstrated the influence of salinity upon trace metal release. Under oxidizing conditions, significant increases in the release of zinc, cadmium, and copper (the latter from only one test sediment) occured at 29‰ as compared to 1‰. The authors attributed this to the increased availability of inorganic ligands at higher salinities, although they point out that increases in cation concentrations could cause the release of trace metals from exchange sites.

The pH of both sediments and the disposal environment can also affect the release of trace metals from dredged material. The pH of reduced sediments tends to be neutral (about 7.0), and upon disposal, changes in both pH and Eh can result in the release of metals. The interaction of Eh and pH is illustrated in Fig. 30. In these studies, Gambrell *et al.* (1976) incubated sediments under controlled conditions and examined changes in metal concentrations. They showed that the fraction of exchangeable zinc at pH 6.5 or 8.0 increased slightly with increasing Eh, but at pH 5.0, concentrations rose dramatically (Fig. 30a). By contrast, changes in the content of reducible copper depended upon Eh and were relatively insensitive to alterations of pH (Fig. 30b). These authors concluded that the response of different metal fractions to pH and Eh values in sediments was variable. Brannon *et al.* (1978), using sediments from Oakland Inner Harbor, also demonstrated increased release of some trace metals with decreasing pH. These data indicate the difficulty of predicting trace metal availability in response to changes in pH and Eh.

In addition to the mobilization of toxic contaminants, dredging and disposal of reduced sediments can deplete oxygen in the water column, a matter that was investigated by the USCOE in 1973-74 during dredging and disposal operations in the Carquinez Strait and San Pablo Bay. Probes were utilized to measure dissolved oxygen down-current from dredging and disposal sites before, during, and after operations. Measurements were verified periodically by Winkler titrations. These studies showed that both dredging and disposal activities reduced dissolved oxygen levels in the nearby waters. Reductions of dissolved oxygen concentrations in local waters as the result of hopper overflow were about 2 mg L^{-1} observed over a duration of about 2 minutes (USCOE, 1976b). Normal values in the Estuary are 8-9 mg O_2 L^{-1}) The disposal of dredged material reduced dissolved oxygen levels in surface waters by a similar amount over the same duration. In the lower water column, however, decreases in dissolved oxygen levels of up to 6 mg L^{-1} were recorded; these low levels lasted 3-4 minutes, but occasionally persisted as long as 11 minutes.

Fig. 30. The influence of pH and Eh on certain fractions for the trace metals zinc (A) and copper (B) in sediments from Mobile Bay, AL. Data from Gambrell *et al.* (1976).



The magnitude of these depressions in dissolved oxygen was influenced by the quality of the dredged material and the dredging equipment employed. For example, the chemical oxygen demand (COD) measured in the sediments disposed at the Carquinez site (4.43% dry wt.) was over twice the COD of the San Pablo Bay sediments. This undoubtedly contributed to the increased frequency and magnitude of dissolved oxygen depressions recorded. The dredging equipment used influences the oxygen demand of the disposed sediments by affecting the extent of contact between the sediments and the water column. Hopper dredges form a slurry and aerate sediments during dredging; the COD of sediments in the hopper may be reduced by 17-68% from *in situ* levels. Injection of water into the hopper immediately prior to the release of material (which helps to jettison the load) further aerates the dredged material and can sometimes produce transient increases in dissolved oxygen levels in the water column immediately after disposal (USCOE, 1976b).

2. Organic Contaminants

The organic contaminants of concern and associated with dredged material are, for the most part, unaffected by charge. Thus, changes in pH, Eh and oxidation state of the sediments with which they are associated have little effect upon their binding and release. The release of organic contaminants may, however, be affected by temperature, the availability of phases suitable for partitioning, and the abundance of particulate matter available for sorption.

Temperature may increase the solubility of sparingly soluble organic contaminants. Among the PCBs, and particularly for lower chlorinated classes of PCBs (monochloro-, dichloro-, trichlorobiphenyls), slight increases in temperature (5^{o}C) may increase solubility by as much as 10% (Samuelian, 1989). While such a change might result in only small increases in the mass of dissolved *vs* particle-bound PCBs, the bioaccumulation factors for such compounds are so high (10^4-10^6) that small increases in the dissolved fraction may translate into relatively large increases in body burdens in the biota.

Changes in phase availability may also affect the release of organic contaminants from sedimentary deposits. Since the hydrophobic organic contaminants partition preferentially to organic matter, increases in dissolved or colloidal organic matter concentrations in sediments, in interstitial water, or in the water column may result in an increase in concentrations of organic contaminants. Whether such changes in organic contaminant concentration would be reflected in an increase in bioavailability cannot be determined easily. Many studies have shown that bioconcentration (the direct accumulation of a contaminant from the water) is dependent upon dissolved concentrations only (Macek *et al.*, 1979). Increased concentrations of dissolved humic materials in the water column have been shown by McCarthy *et al.* (1985) to actually cause a *decrease* in bioconcentration of PAHs by planktonic organisms.

Increased concentrations of suspended particulate matter in the water column might be expected to cause an overall increase in the concentration of organic

contaminants; however, due to adsorption, it might be expected that the pollutants associated with the particulates would not be available to the biota. Some data exist to support this contention. For example, Califano *et al.* (1982) showed that bioconcentration of PCBs (Aroclor 1254) by striped bass was decreased when particles were added to the water. However, studies of the adsorption of organic contaminants on particulate matter would suggest that increases in particle concentration to high levels might actually result in reduced adsorption and an increase in the concentration of dissolved material. This phenomenon is known as the "solids effect" (O'Connor and Connolly, 1980).

The solids effect is an empirically described phenomenon in which the partition coefficient (k_d) for a contaminant (e.g., PCBs) and suspended solids has been shown to decrease with increasing concentrations of suspended material. Although described initially from laboratory studies, the solids effect has been suggested as occurring in natural surface waters of the Great Lakes and in the Hudson River (Samuelian, 1989). Although much effort has been expended in an effort to explain why such a phenomenon might occur, there is no plausible explanation at hand.

C. THE LONG-TERM RELEASE OF CONTAMINANTS

The long-term release of contaminants from dredged material disposed in San Francisco Estuary is an important issue. Several studies conducted at disposal sites in the U.S. have shown that metallic and organic contaminants are retained within consolidated disposal mounds (e.g., the New York Bight and Puget Sound; (O'Connor and O'Connor, 1983; Brannon *et al.*, 1985; Truitt, 1986b; Gunnison *et al.*, 1987). However, the dispersive nature of the disposal sites within the San Francisco Estuary ensures that a significant fraction of disposed material is transported throughout the system. There are physical, chemical, and biological factors that act over long periods to mobilize contaminants from dispersed dredged material, and these may have a profound effect on the availability of contaminants in dredged material to organisms.

The long-term release of contaminants from dispersed dredged material has received little study to date, due to the difficulties of establishing controlled experimental conditions. Brannon *et al.* (1978) conducted a laboratory study to investigate the long-term release of trace metals from sediments collected at several dredging sites around the country, including the Oakland Inner and Outer harbors. Sediments and water collected from each site were placed in 20 L, aerated polyethylene containers, two of which were stirred to simulate agitated conditions. Water samples were collected from the containers after 120 and 240 days, and the mass of dissolved trace metals determined. These results were compared to the results of sequential leaching experiments for each sediment.

The study concluded that the long-term release (on a mass basis) of most metals was determined largely by the initial release of exchangeable metals. Analysis of 240-day samples indicated a poorer relationship with sequential leaching fractions than did the 120-day samples, indicating that over a longer period, aquatic chemistry of contaminants (as opposed to original sediment concentrations) was an important factor in remobilization. The agitated sample from Oakland Outer Harbor did not demonstrate significantly different trace metal release compared to the sample tested

under quiescent conditions; however, agitation of the sample from Oakland Inner Harbor caused increased acidity, resulting in the enhanced release of several trace metals. It should be kept in mind that this study examined only dissolved contaminants and that the particulate fraction could also have included contaminants produced by long-term remobilization processes.

Brannon *et al.* (1978) state that verifying these laboratory relationships in the field is difficult if not impossible, and laboratory tests are limited to indicating the potential for release of contaminants in dredged material. This is particularly true in the Estuary, given the dispersive nature of the disposal sites. The situation is further complicated by the variety of disposal locations, each with different physical, chemical, and biological characteristics; thus, generalizations based upon data from a particular field disposal site are not possible. Laboratory-based research presents similar problems; such studies cannot recreate the constantly changing environment to which disposed material is exposed throughout the Estuary.

An important factor affecting the long-term availability of contaminants from material disposed in the Estuary is exposure to higher Eh values under stable conditions of pH. Such conditions may foster the release of certain trace metals associated with dredged materials, particularly metal sulfides and organic complexes. The data of Serne and Mercer (1975), from studies conducted on a finer timescale than those of Brannon *et al.* (1978), indicate that the release of some metals may be due to redox reactions that occur over several days. For example, the release of cadmium in a six-day elutriate test was about 15 times greater than that during a 24-hour test. Although it is not clear how well the elutriate tests mimic the long-term release of contaminants in the field, these data indicate the need to understand the kinetics of contaminant release when assessing the potential availability of contaminants from disposed material.

Serne and Mercer (1975) point out that salinity may affect the long-term release of trace metals. During periods of high Delta outflow, sediments in the northern reach of the Estuary may be exposed to relatively low salinities. As Delta outflow declines during the spring and summer, higher salinities could stimulate the release of trace metals from the oxidized surface sediments, which may include previously disposed dredged material.

The dynamic state of the sediments in the Estuary affects the susceptibility of contaminants to microbial metabolism. There have been few direct studies of the microbial metabolism of sediment-bound contaminants. Both laboratory and field studies show that microbial metabolism of toxic organic materials (PCBs and PAHs) can occur in both aerobic and anaerobic sediments (J. Brown, General Electric Co., personal communication). However, bacterial metabolism can also result in the transformation of contaminants such as mercury from the elemental form to methylmercury, a compound substantially more mobile and toxic than elemental Hg (Microbial activity in sediments is controlled by several factors, including pH, Eh, temperature, and nutrient concentrations [Pritchard, 1987]). As these factors vary considerably in Bay sediments, the microbial metabolism of sediment-bound contaminants will also differ from site to site.

D. LOADING ESTIMATES FOR CONTAMINANTS FROM DREDGING AND DISPOSAL

The remobilization of contaminants from dredged sediments in the Estuary represents a finite contaminant load in the system. Comparison of this load to contaminant loads from other sources is difficult, as double-counting is involved (contaminants in dredged sediments are originally derived from other quantified sources, either recently or in the past; see Gunther *et al.*, 1987). Nevertheless, attempts have been made to quantify both the gross amounts of contaminants that may be remobilized due to dredging and disposal activities and their potential bioavailabilities. Gunther *et al.* (1987) estimated the loads of toxic contaminants to the San Francisco Estuary from various sources. In the absence of reliable local data, they assumed that between 1 and 10% of the contaminants transported in dredged materials may be remobilized in the Estuary. On this basis, the dredging and disposal of sediments was found to represent a relatively minor contribution to the overall loads of trace metals, PCBs, and PAHs in the Estuary (Table 17). However, it was noted that considerable uncertainty surrounded the estimates not only of the remobilization of contaminants from dredge spoils, but also of total loads from other sources. In many cases, the available data do not permit the calculation of comparable loading estimates. For example, the riverine loads of trace metals (which are considerable in many cases) do not reflect loads entering sorbed to suspended particles, because no data are available from which to calculate these (Gunther *et al.*, 1987).

Segar (1988) has recently argued that these estimates of total loads from the remobilization of contaminants associated with dredging and the disposal of sediments in the Estuary are too low. He provides further estimates (Table 17), based upon the following assumptions:

(i) the average concentrations of contaminants present in dredged material are unchanged from those employed initially by Gunther *et al.* (1987);

(ii) losses of dredged material and its associated contaminants by burial at the Alcatraz site are assumed to be 20% of the total amounts dredged and disposed in any one year;

(iii) of the remaining 80% of the contaminants not lost through mounding at Alcatraz, only a portion of each of the trace metals is sorbed, while the rest is residual in nature. Data for the percentages of metals present in the residual phase in sediments were abstracted from Eaton (1979) and Serne and Mercer (1975), and were as follows: cadmium, 5%; copper, 60%; lead, 50%; mercury, 80%; nickel, 85%; and zinc, 60%;

(iv) all of the PCBs and PAHs are present in adsorbed forms; and

(v) all of the contaminants not present in the Alcatraz mound and those not in the residual phase are assumed to be both remobilized and bioavailable.

This approach can be considered conservative, providing an estimate of the <u>maximum</u> potential load that could be associated with dredging and disposal: the <u>actual</u> load is almost certainly less than the values estimated by Segar (1988). Because local data and those generated elsewhere suggest low rates of remobilization and/or bioavailability of contaminants in dredged material (see Anderlini *et al.*, 1975a, 1975b, discussed below; Rubinstein *et al.*, 1983; Lake *et al.*, 1985; O'Connor and Squibb, 1988), assumption (v) above will result in an over-

Table 17. Inputs (tonnes per year) of selected contaminants to the San Francisco Estuary. Data from Gunther et al. (1987), except as noted. Bioavailable dredged material loadings represent the potentially readily bioavailable toxicants calculated by adjusting total loading estimates from Gunther et al. (1987), assuming:

A. 20% of the contaminant is buried in accumulated sediments at the Alcatraz dumpsite;and

B. Residual phase contaminants are not potentially bioavailable. Residual phase estimated as 60% of total copper, 80% of mercury, 5% of cadmium, 50% of lead, 60% of zinc, 85% of nickel, and 0% of PCBs and PAHs (Segar, 1988).

Contaminant	Atmospheric	Non-Urban	Riverine	Urban	Point Source	Dredged Material	Dredged Material (Segar, 1988)	Bioavailable Dredged Material (Segar, 1988)
Copper	1.9 - 3.1	51 - 581	203	7.0 - 59	18 - 31	1 - 10	100	32
Mercury	N/A	0.15 - 1.7	1.2 - 3.0	0.026 - 0.15	0.18 - 0.8	0.01 - 0.1	1	0.16
Cadmium	0.14 - 0.35	0.52 - 6.0	5.5 - 27	0.3 - 3.0	1.9 - 4.0	0.02 - 0.2	2	1.5
Lead	6 - 21	31 - 358	30 - 66	30 - 250	11 - 17	1 - 10	100	40
Zinc	16 - 32	126 - 1435	272 - 288	34 - 268	70 - 74	3 - 30	300	96
Nickel	N/A	N/A	74 - 82	N/A	21 - 29	2 - 20	200	24
PCBs	0.12 - 0.75	N/A	N/A	0.006 - 0.4	N/A	0.00067 - 0.0067	0.067	0.054
PAHs	0.8 - 4.8	N/A	N/A	0.5 - 5.0	N/A	0.05 - 0.47	4.7	3.8

N/A - Data not available.

estimate. In addition, this reasoning would require that the non-residual fraction of naturally resuspended sediments also be considered as a source of contaminants to the Estuary. In the absence of improved estimates of the actual remobilization of contaminants in dredged material in the Estuary, or standard assumptions related to making such estimates, all estimates produced to date should be treated with caution, as noted by Gunther *et al.* (1987).

It may be that the loading of contaminants due to dredging and disposal operations is different for maintenance and new work projects. Maintenance dredging involves recently deposited material and reflects the general level of particulate contamination in the Estuary and the local sources of contamination for a particular dredging project. New work dredging may re-introduce to the Estuary sediments that have been buried for extended periods. These older sediment deposits might include contamination from historic activities, as was discussed in Section IV.B.2. for the Todd Shipyard site in Oakland Inner Harbor. It is also possible that new work dredging may redistribute sediment that contains lower concentrations of contaminants than concentrations typical of material from maintenance dredging.

E. SUMMARY

Potentially toxic contaminants are present in dredged material in many forms, which vary in their susceptibility to mobilization and in their bioavailability. Sequential extraction techniques cannot provide a definite picture of the physico-chemical state of trace metals, but they do show that the physico-chemical state of metals varies between sediments. Such differences in physico-chemical state may influence bioavailability. Site-specific analyses will be required to assess the potential for metals mobilization from any particular project. However, a significant portion of the trace metals in the sediments of the Estuary (with the exception of cadmium) has been found to be lattice-bound; such contaminants are generally considered to be immobilized, and unavailable for exchange, release, or bioconcentration. Organic materials are distributed in a different manner from trace elements in sediment, being found almost exclusively in adsorbed form.

The behavior of sediment-associated contaminants upon disposal is complex and cannot be easily determined by laboratory experiments. However, oxidation/reduction potential (Eh), pH, and conditions in the disposal environment are important in determining the release of contaminants to the environment. Salinity, in particular, has been shown to influence the release of some trace elements. Short-term depressions in dissolved oxygen levels have also been observed at dredging and disposal sites, particularly in the lower portion of the water column. These short-term depressions are influenced by the oxygen demand of the sediments, and the type of dredging equipment utilized.

The long-term fate of contaminants mobilized by disposal operations has received little study, particularly in the field. This issue is particularly important in the San Francisco Estuary, as the dispersive nature of the disposal sites presently employed ensures maximum exposure of contaminated materials to an oxidizing environment. Although there are certain mechanisms that may quickly remove some

trace metals from the water column under such conditions, the long-term processes affecting the transport and fate of contaminants are poorly understood.

As data on the remobilization of contaminants from dredged materials are so poor, the accurate quantification of contaminant loads from dredging and disposal is impossible. Controversy has existed on this issue, and differing estimates of the loads of remobilized (potentially bioavailable) contaminants have been produced. In the absence of reliable local data on the rates of remobilization of contaminants in the Estuary and the proportions of the contaminants released which are bioavailable, such estimates should be treated with caution (Gunther *et al.*, 1987). These questions are being addressed on the national level as efforts proceed in the attempt to derive "sediment quality criteria" for inclusion in the evaluative process for dredged material disposal (Chapman, 1984; Pavlou, 1984; Spies, 1989).

2. Accumulation of Contaminants from Disposed Dredged Material

Contaminants only affect aquatic organisms when they are available to the organism(s) in a form that can disrupt critical surface functions (e.g., respiratory gas exchange, and olfaction) or can be accumulated to concentrations that cause acute or chronic effects. This section of the report discusses the availability to the biota of metallic and organic contaminants in disposed dredged material. The discussion proceeds from mechanisms for contaminant bioaccumulation to a summary of factors that determine the bioavailability of sediment-borne contaminants to aquatic biota.

A. MECHANISMS FOR ACCUMULATION

Organisms accumulate contaminants *via* one or both of two routes; directly from the water (*via* respiratory epithelia and other highly vascularized epidermal tissues) or through the gut after the ingestion of contaminated food. Accumulation of contaminants directly from the water is referred to as "bioconcentration." Accumulation from the food is referred to as "food-web transport." The general term "bioaccumulation" refers to the total accumulation of contaminant material from all sources, *via* all pathways.

Bioconcentration in fishes and invertebrates occurs across the highly vascularized epithelia of the gills, and is driven by diffusion gradients (in the case of metals) or by equilibrium partitioning of hydrophobic organic chemicals from water to gill tissue. Once contaminants have entered the epithelia of the gill, they move to the circulatory system and are transported throughout the body of the organism. Movement of metals through the epithelium of the gill is probably driven by active transport processes as well as by diffusion; movement of organic contaminants across the gill probably occurs as the result of "facilitated transport" involving the normal cycling of macromolecules within cells. Diffusion gradients are maintained since contaminants, once inside the organism, are removed from the blood by the tissues, particularly the liver and kidney.

Aquatic biota are capable of concentrating both metals and organic contaminants to levels substantially greater than the concentration in the water. In the case of metals, bioconcentration factors (BCF) may range from low values of 5 or 10

(e.g., for Ni) to more than 100,000 (for Hg; see summaries in Callahan *et al.,* 1979 and O'Connor and Rachlin, 1982). The BCF is the concentration of the metal in the body of the organism, at equilibrium, compared to the concentration of the contaminant in the water (on a gram-for-gram basis, tissue *vs* water).

Bioconcentration factors for organic contaminants depend upon the nature of the compound in question, in particular, the extent to which the compound is soluble in organic solvents (e.g., lipids). In the case of the PCBs, BCF values may range from about 100 for the lower chlorinated PCBs to more than 500,000 for PCBs in the hexachloro- and heptachlorobiphenyl classes. That is to say, if a particular hexachlorobiphenyl molecule were dissolved in the water at concentrations of 1 part per trillion (1 ng L^{-1}), it might become concentrated in the flesh of a fish to a level of 0.5 parts per million (0.5 $\mu g\ g^{-1}$). Bioconcentration factors for other lipophilic organic compounds are of the same range. The BCF for DDT may be as high as 10^6, while that for dieldrin is about 10^4, and the BCF for a range of PAH compounds is from 10^3 to 10^5.

Food chain transport ratios for both metals and organic contaminants are much lower than BCFs. This is due to the fact that cross-gut assimilation of many contaminants may be inefficient (e.g., the assimilation efficiency of Cd across the gut may be as low as 5%), and contaminants assimilated from the gut are transported first to the liver, where a large fraction may be eliminated immediately *via* the bile (O'Connor and Rachlin, 1982).

Studies from marine, estuarine, and freshwater systems have demonstrated rather conclusively that the major route for contaminant transport in aquatic systems is *via* the food chain. In studies of PCB transport in lake trout from the Great Lakes, for example, Thomann and Connolly (1984) concluded that more than 90% of the PCB accumulated by trout derived from the food chain. O'Connor (1984) and Pizza and O'Connor (1983) estimated that from 50 to 85% of the PCB in Hudson River striped bass came from contaminated food. For metals, it is apparent that most of the mercury assimilated by aquatic biota comes from the food chain, and studies of blue crabs in the Hudson River (Hazen and Kneip, 1980) showed that the primary route for Cd transport was via the food.

The dominance of food chain transport over bioconcentration of contaminants in natural systems is the result of several factors, the most important of which are the tendency for most contaminants to be associated with particulate matter in natural systems, and the (relatively) large concentration of particulate matter in natural surface waters. Assessment of the impact of contaminants from dredged material on the biota of the San Francisco Estuary, therefore, must concentrate on the following pathway: dredged sediments to deposited/ suspended sediment to prey to predator (or, in the case of filter feeders and deposit feeders: dredged sediments to deposited/suspended material to consumer). Little is known regarding the structure of food webs in the Estuary; additional study will be required in order to draw any firm conclusions about mass transport of contaminants among and between compartments.

B. BIOAVAILABILITY OF SEDIMENT-BORNE CONTAMINANTS TO ORGANISMS

Not all contaminants on or in sediments are available to the biota. In order for bioconcentration to occur it is necessary that the contaminant in question be in the dissolved state, or at least associated with the dissolved fraction of organic material in the water column. Thus, matrix-bound metals in sediments or suspended sediments are not available for bioconcentration, nor are organic contaminants that are adsorbed to the surfaces of suspended or deposited particulate matter (Fulk *et al.,* 1975; Rubinstein *et al.,* 1983).

Metals in disposed dredged materials in the Estuary will, for the most part, be particle-bound. Some undetermined fraction will be present dissolved in pore waters. Upon dredging, and upon subsequent release at the dump site, metals in dredged material will be subjected to a significant change in chemical environment (see Section V.D.1.B., above), including oxidation and change in Eh. Solubilization of metals will occur as part of the disposal process and may result in an increase of dissolved metals concentrations downcurrent from the dumpsite as the sediment plume disperses. The metals most likely to show increases are those with higher solubilities, including Cd, Cu, and Zn (Segar and Cantillo, 1976). Increases in dissolved metals concentrations in the water column following disposal of dredged material may be assumed to have the potential to result in an increase in the amount of metals accumulated via bioconcentration. BCF values for Cd and Cu are relatively low for marine fishes (3,000 and 700, respectively; Chapman *et al.,* 1968), but may be high for marine invertebrates (250,000; Chapman *et al.,* 1968). BCF values for zinc in aquatic biota vary widely (500 - 100,000; Callahan *et al.,* 1979); however, zinc is an essential element, and is well regulated by most organisms (O'Connor and Rachlin, 1982).

In the only local study of bioaccumulation in the Estuary that was directly related to dredging operations, Anderlini *et al.* (1975a) investigated the concentrations of trace metals in local and transplanted invertebrates before, during, and after two dredging operations in Mare Island Strait between September 1973 and May 1974. Concentrations of nine trace metals (silver, arsenic, cadmium, copper, mercury, nickel, lead, selenium, and zinc) were monitored in sediments and the following native organisms: the clam *Macoma balthica*, the mussel *Ischadium demissum*, the worm *Neanthes succinea*, and the amphipod *Ampelisca milleri.* In addition, mussels (*Mytilus edulis*) were transplanted from Tomales Bay to Mare Island Strait.

The two dredging operations examined in this study coincided with periods of heavy rainfall, resulting in significant changes in salinity and particulate loading in the Mare Island Strait. These factors are known to affect the uptake of trace metals by many organisms (see review by Phillips, 1980), and organisms both within and outside the zone of dredging showed similar temporal changes in tissue concentrations of metals. Transplanted *M. edulis* demonstrated similar accumulation of metals within and outside the dredging zones in Mare Island Strait, suggesting that the effect of change in salinity on the uptake of elements could not be differentiated from any impact of the dredging operations.

In a companion study, Anderlini *et al.* (1975b) examined the uptake of twelve trace metals, PCBs (as Aroclor 1254), and DDT (including DDE and DDD) by native and transplanted benthic invertebrates during an experimental dredged material disposal operation in Central Bay. The organisms present in consistent quantities for study were the clam *Macoma nasuta*, the worm *Pectinaria californiensis*, and the sea pen *Stylatula elongata*. Six sampling stations were employed, located around the disposal site in two rings of three stations each. In addition, the mussel *M. edulis* was transplanted at three different depths at the six stations to investigate the bioavailability of dissolved contaminants and those associated with suspended particulates. It was assumed that the outer stations (200 m from the disposal site) would be affected less by disposal operations compared to the inner stations (100 m from the disposal site).

With the exception of DDE, the mean concentrations of contaminants in the tissues of the various species exhibited no significant statistical differences between the inner and outer stations over the period of the disposal operation (Anderlini *et al.* (1975b) The authors concluded that the disposal operation did not increase the bioavailabilities of contaminants other than DDE at the locations studied. Concentrations of DDE in mussels (*M. edulis*) decreased throughout the study area over the period of disposal, but the deceases observed in samples close to the disposal site were smaller than those in more distant samples. This effect persisted for less than one month. In addition, both copper and iron concentrations in surface sediments were found to be elevated in the disposal area compared to more distant sites, and short-term increases in concentrations of chlorinated hydrocarbons and of dissolved cadmium, copper, and lead were observed in water samples taken from within the spoil plume at disposal. It was concluded that the disposal activities redistributed contaminated sediments but did not give rise to observable increases in contaminant bioavailabilities, at least for the sites and under the conditions studied (Anderlini *et al.*, 1975b). It should be noted here that the post-disposal samples were collected two weeks after disposal; thus, any short-term increases in tissue concentrations that may have occurred would not have been observed. In addition, the organisms studied were composited employing a relatively small number of individuals (10-20 in most cases) for each sample. The effect of this is to increase within-sample variability, rendering differences in contaminant concentrations between samples difficult to detect (Gordon *et al.*, 1980; NAS, 1980).

The organic contaminants of concern in the Estuary will, for the most part, remain adsorbed to particulate matter, whether in the deposited or suspended state (Fulk *et al.,* 1975). This renders them essentially unavailable for bioconcentration from the water column, and available to the biota almost exclusively through food-chain transport (Rubinstein *et al.,* 1984; O'Connor and Pizza, 1987; Stein *et al.,* 1987). In an elegant experiment, Rubinstein *et al.* (1984) studied the availability to spot (*Leiostomus xanthurus*) of PCBs from dredged sediment. Spot were exposed 1) to the contaminated sediment and fed clean food, 2) to clean sediment, and fed PCB-contaminated food, 3) to contaminated sediment for a period of time, and then fed PCB-contaminated food, or 4) to clean sediment for a time, and then fed contaminated food. In all cases it was determined that exposure to water in contact with contaminated sediment led to very little PCB uptake. However, the increase in PCB body burdens due to feeding the fish PCB-contaminated food was dramatic, and was equivalent in all groups that received contaminated food. That is, the increase over the

previous baseline of the PCB burden was essentially the same, whether the fish had previously been exposed to clean sediment or contaminated sediment. These data, in combination with earlier data on Cd and PCB accumulation from different types of sediment (Rubinstein *et al.*, 1983) serve to demonstrate that PCB availability from dredged sediments is very low; if the fish are going to accumulate contaminants, then the accumulation is most likely to derive from the consumption of contaminated food. Similar conclusions can be drawn for other organic contaminant classes, such as chlorinated pesticides (Fulk *et al.*, 1975) and PAHs such as benzo(a)pyrene, phenanthrene, and fluoranthene (Stein *et al.*, 1984, 1987; O'Connor and Squibb, 1988).

The availability of sediment-bound metallic and organic contaminants via the food chain may be substantial. As shown in numerous cases, both filter-feeding and deposit - feeding bivalve molluscs accumulate metallic and organic contaminants readily when exposed to water containing contaminated sedimentary material (Lake *et al.*, 1985; Koepp *et al.*, 1987; Phillips, 1988). In most such cases with bivalve mollusc accumulation assays it is essential to keep in mind that most of the accumulation observed is food-chain (particulate) transport, rather than bioconcentration of dissolved material from the water (Lake *et al.*, 1985).

The studies of Lake *et al.* (1985) showed that the disposal of dredged material gives rise to increased bioavailabilities of contaminants, at least on a local scale. In most cases, certain organic contaminants appear to be of greater potential bioavailability, perhaps because they are all surface-adsorbed to particulates, in contrast to trace metals, which were present partially in the residual (unavailable) fraction of sediments. Lake *et al.* (1988) examined the concentrations of PCBs, PAHs, and trace metals in transplanted *M. edulis* and in the polychaete *Nephtys incisa* before and after disposal of heavily contaminated dredged material from Black Rock Harbor, Connecticut, at the Central Long Island Sound (CLIS) disposal site offshore from New Haven. Transplanted mussels were suspended 1 m off the substrate in polyethylene baskets and polychaetes were collected at 4 stations (the center of the site, 200 m, 400 m, and 1,000 m down-current), to represent a gradient of exposure to disposed material. The principal objective of this work was to determine the ability of laboratory studies to predict the availabilities of contaminants from disposed dredged material in the field, rather than to investigate contaminant uptake rates *per se*.

PCBs and certain PAHs were found to be available to *M. edulis* in higher concentrations during and just after disposal when compared to pre-disposal levels or to the concentrations accumulated by mussels at the reference site. Concentrations of PCBs (Aroclor 1254) in mussel tissues reached 1,080 ng g^{-1} (dry wt.) immediately after completion of the disposal operation at the 1,000-m site., (initial concentrations were about 400 ng g^{-1} dry wt., prior to disposal). Additional mussels collected two weeks later had PCB concentrations greater than 1,000 ng g^{-1}. A similar pattern was seen for the PAH benzo[a]pyrene, but several other contaminants (fluoranthene, phenanthrene, copper, cadmium, and chromium) were not bioaccumulated significantly by mussels.

The polychaete *N. incisa* also exhibited elevated concentrations of PCBs subsequent to the disposal operation. Samples at the reference site contained 290

ng g^{-1} dry wt., while concentrations at the 1,000-m site reached 630 ng g^{-1} dry wt. and those at the 400-m site reached 1,000 ng g^{-1} dry wt.. Higher concentrations of fluoranthene, phenanthrene, and benzo[a]pyrene were also detected in *N. incisa* close to the disposal site, but as with *M. edulis*, no detectable increase occurred in the concentrations of copper, cadmium, or chromium in *N. incisa* due to the disposal operation. By comparison to concentrations in *N. incisa* from the reference station, the levels of both PCBs and PAHs apparently remained elevated at sampling stations close to this non-dispersive disposal site for over 2 yr after disposal operations had ceased. However, it should be noted that statistical comparisons of contaminant levels were not performed.

Based upon the fact that both suspended and deposited sediments, as well as most of the biota sampled from the Estuary contain measurable concentrations of metallic and organic contaminants greater than concentrations found in "background" areas (e.g., Tomales Bay, Bodega Bay), it is reasonable to assume that food-chain transport of metals and organic contaminants is an ongoing phenomenon in the Estuary.

That metals are readily available to the benthos of the Estuary is apparent from studies carried out by Luoma and co-workers (Luoma and Bryan, 1978; Luoma and Cain, 1979; Luoma and Cloern, 1982; Luoma *et al.,* 1983, 1985; Luoma and Phillips, 1988). These data suggest that fish preying upon the bivalves should also contain measurable and elevated metals concentrations. This appears to be the case for some of the metals, such as Hg and Cd, but not for Cr, Cu, Pb, or Ag (Long *et al.,* 1988). Chromium, Cu, Pb, and Ag concentrations in starry flounder and white croaker were close to the concentrations observed in the control environment of Bodega Bay. It is interesting to note that Luoma and Phillips (1988) suggest that Cu may be unusually bioavailable to bivalves in the South Bay portion of the Estuary, but that the elevated concentrations of Cu are apparently not transported to either starry flounder or white croaker. Data from Long et al. (1988) show that Cu concentrations in starry flounder and white croaker (76 - 118 $\mu g\ g^{-1}$) differ little, if any, from concentrations measured in control populations from Bodega Bay (70 $\mu g\ g^{-1}$).

Food chain transport of organic contaminants in the San Francisco Estuary is precisely what might be expected from values reported in the literature for other systems. Data from the fishes and fish food organisms in the Hudson River (O'Connor, 1984; O'Connor and Pizza, 1987; O'Connor and Samuelian, in preparation) suggest that fish flesh at steady-state might contain from 1 to 2 times the PCB concentration found in food organisms (data from tomcod [*Microgadus tomcod*] ; white perch [*Morone americana*], and striped bass [*Morone saxatilis*]; see also Rubinstein *et al.,* 1984). In the San Francisco Estuary body burdens of PCBs in mussels ranged from about 0.2 to 1.5 $\mu g\ g^{-1}$ (dry wt.). If mussels were assumed to represent bioaccumulation in benthic invertebrates in the Estuary, then one might expect striped bass flesh to contain similar concentrations (Pizza and O'Connor, 1983). Converting the available data to $\mu g\ g^{-1}$ dry wt. for flesh (Whipple, *et al.*, 1983; Crosby *et al.,* 1986), striped bass PCB concentrations in the Estuary range from about 0.1 to 1.0 $\mu g\ g^{-1}$, values very similar to those seen in mussels (Hayes and Phillips, 1986). Similar comparisons made for DDT yielded essentially the same result; organochlorine contaminants in fishes from the San Francisco Estuary provide evidence that these pollutants are transported to the

fishes via the food chain, and that there appears not to be any significant magnification of concentration as one moves from one trophic level to another within the Estuary. Insufficient data were available for evaluation of other organic contaminants (e.g., toxaphene, chlordane, and PAHs).

3. Sediment Toxicity

Short-term or acute toxicity to one or more species during laboratory exposures implies that at greater contaminant dilutions, and over longer periods, there could be effects on the species under consideration or more sensitive organisms. However, once released into the Bay-Delta, the contaminants causing effects in bioassays undergo extreme dilution and may be transformed by photochemical degradation, or by metabolism by microbes and multicellular organisms. In addition, resident species may have undergone genetic adaptations, making them more resistant to the contaminants than the bioassay organisms. Furthermore, sublethal effects such as overall fitness, and the ability to reproduce or grow may not be measurable in short-term bioassays. Lower concentrations of contaminants over longer periods might result in more significant population effects than indicated by short-term bioassays. Also, there may be interactive effects of contaminants that are not predictable from bioassays of single compounds or elements. Other traditional methods of study, such as community-level surveys, measurement of contaminants in tissues of organisms, and *in situ* and sediment bioassays also cannot provide evidence of significant system-wide biological effects of contaminants.

In recent years the use of sediment bioassays to gauge the toxicity of sediments has increased. This is particularly true for sediments considered for dredging and dumping elsewhere within the Bay, or offshore. These bioassays use molluscs, fish, and crustaceans to characterize sediments. The end-points used may be mortality or various sublethal effects on behavioral, reproductive, or developmental processes. These assays have been utilized in ecological assessments of sediment contamination using "synoptic" approaches such as the "sediment triad concept" (Chapman *et al.*, 1987) and the "apparent effects threshold" (AET; PTI, 1988). The results of sediment bioassays conducted in the San Francisco Estuary are summarized below, emphasizing the two most commonly used assays: the amphipod bioassay and the oyster or mussel larvae bioassay. This topic is covered in detail in Davis *et al.* (1989); see also Swartz (1988) and Spies (1989).

Significant toxic responses have been demonstrated in many of the tests using sediments from the Estuary, and these responses have been attributed to sediment contamination. These results suggest a need for control of the discharge of toxic contaminants to the Estuary, and elimination of in-Bay disposal of contaminated dredged material. It has also been pointed out that interpretation of these results is confounded by the fact that physical characteristics of the sediments, rather than contamination, may also be responsible for toxic effects upon bioassay organisms (De Witt *et al.*, 1988; Spies, 1989).

There have been two general types of sediment bioassays performed in the Estuary. So-called "bulk" or solid-phase assays use relatively undisturbed sediments that are removed from the Bay-Delta and placed in aquaria in the laboratory with test

organisms. In elutriate bioassays, mixtures of sediment and seawater (typically either 250 g L^{-1} or 20 g L^{-1}) are made, shaken, allowed to settle and the supernatant used for testing. Survival, ability to rebury, growth and reproduction, and abnormalities present after a specified period of time in bioassay organisms are used to compare sediments from various areas, and to make judgements about the appropriateness of specific actions, such as dredging. The most common endpoint is survival, and the most common testing periods are 48 h, 96 h, and 10 d. Some of these studies have been reviewed recently by Long *et al.* (1988); however, a more recent study (Long *et al.*, unpublished data) and studies from several proposed dredging projects, include a large number of assays and endpoints that had not been implemented at the time of the review of Long *et al.* (1988).

Testing of sediments at three Bay sites (San Pablo Bay, Oakland Harbor area, and Islais Creek) was undertaken by Chapman *et al.* (1987) utilizing two bioassays: survival of the amphipod *Rhepoxinius abronius* and survival of mussel larvae. Survival of amphipods in the sediments from San Pablo Bay and the area adjacent to the Oakland Harbor were relatively high (>86%), and not significantly different from a control sediment taken from the state of Washington (94%). Amphipods exposed to the Islais Creek samples, however, demonstrated significantly poorer survival (9.4%). In the mussel larvae bioassays, a clear pattern was observed with percent survival ranging from 51 to 83% in San Pablo Bay samples, 24 to 49% in the Oakland samples and 6 to 14% in the Islais Creek samples. All these values were significantly lower than the seawater control, but a sediment sample from a control site was not tested. The Islais Creek stations had the highest concentrations of lead, mercury, silver, PCBs, and PAHs. Other elements (e.g., copper) showed elevated sediment concentrations at Islais Creek. For most chemicals measured, normalization to total organic carbon (TOC) reduced differences between stations, but the above-mentioned substances still had significantly elevated concentrations at Islais Creek. The sediments at Islais Creek had generally much higher proportions of silt and higher concentrations of TOC.

In planning for the homeporting of the USS Missouri battle group in San Francisco Bay, a variety of sediment bioassays were performed. In these tests, sediment samples were taken from several depths by core and subsequently combined to make up samples representative of the material to be disposed. Several stations were located within each of three areas: Treasure Island, Alameda, and Hunters Point. When compared to an offshore reference sediment, samples from two Hunters Point stations and two Alameda stations had significantly lower survival of the amphipod *Rhepoxinius abronius*. Mean survival after exposure to sediments from Hunters Point stations was 54%; from Alameda, 66.5%; and from Treasure Island, 52%. However, considerable variation within these sites was evident. Similar results were obtained with the oyster larvae bioassay: significantly elevated abnormalities were observed in two Treasure Island and two Hunters Point stations. Several other sediment bioassays were carried out with these sediments. Mysid bioassays gave different results at different testing times and are not considered further here. The bivalve *Macoma nasuta* and the polychaete worm *Nephthys caecoides* both proved to be very hardy and did not exhibit significant differences between stations.

Correlation and multiple regression analyses were undertaken in order to determine if there were any inter-relationships among the bioassays performed, the

biological uptake of contaminants, and the chemicals measured in the sediments from the 16 stations used in this study (Spies, 1987). There were no significant relationships found among the various bioassays used, although the greatest similarities were found between the oyster larval and sanddab survival. The strongest correlations between sediment chemicals and toxicity were for copper and hydrocarbons in sediments and mortality of the sanddab. Zinc bioavailability was correlated with oyster and mussel abnormalities, and cadmium was correlated with sanddab and amphipod mortality. Caution was urged in interpreting the results of such analyses as multiple comparisons are likely to yield some spurious relationships. Also, correlation does not prove cause and effect. The elutriate testing results may not be comparable to some other studies, as a mixture of 250 g sediment in one liter of seawater was used here, while other studies (e.g., Chapman *et al.*, 1986) used a mixture of 20 g of sediment in one liter of seawater.

Another major study of sediment contamination was carried out with sediments from the Oakland Inner Harbor and the Alcatraz dredged materials disposal site in order to assess the suitability of these materials for ocean disposal (EVS, 1988). Solid-phase bioassays were carried out using *Rhepoxinius abronius*, the polychaete *Nephthys caecoides*, and the mysid *Acanthomysis sculpta*. Suspended particulate-phase bioassays were carried out with *Rhepoxinius abronius*, bivalve (mussel and oyster) larvae, and the sanddab *Citharichthys stigmaeus*. Results of the assays using harbor sediments were compared to those of sediments from the Alcatraz site and the proposed offshore disposal sites. Bioaccumulation tests were also carried out by placing clams, *Macoma nasuta*, and polychaete worms, *Nephthys caecoides*, in the sediments for 20 days, and analyzing them to determine if they contained significantly elevated concentrations of contaminants relative to those placed in reference sediments.

In the suspended particulate bioassays, significantly greater mortality of *C. stigmaeus* and mussel larvae occurred in some harbor sediments relative to ocean sediments. In the solid phase bioassays, there were significantly elevated mortalities of *R. abronius* and *N. caecoides* in all harbor sediments. *Macoma nasuta* placed in harbor sediments contained elevated concentrations of chromium, lead, zinc, and chlorinated pesticides relative to controls; for *Nephthys caecoides*, only silver was elevated in some sediment treatments. It should be noted that the detection limits for petroleum hydrocarbons were 5 to 15 $\mu g\ g^{-1}$ tissue (wet wt.). In comparisons of the Alcatraz dump site and offshore sediments, significant mortality in the suspended particulate bioassays were seen with *A. sculpta*, *C. stigmaeus,* and oyster larvae. For *M. nasuta*, elevated concentrations of lead, DDE, DDD, and dieldrin were observed in one sample each out of the four tested. Apparently, different methods for detecting hydrocarbons in tissues were used in the evaluation of the Alcatraz sediments, as detection limits for individual polynuclear aromatic hydrocarbons were from 0.001 to 0.002 $\mu g\ g^{-1}$ tissue. Using this method, one of the four test sediments produced elevated concentrations of acenaphthene, acenaphthylene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene in clam tissues. Apparently, the samples were not analyzed for the carcinogenic PAH benzo(*a*)pyrene.

A second study to assess the potential toxicity of dredged sediments from Oakland Inner Harbor was also performed (Word *et al.*, 1988). Sediments were

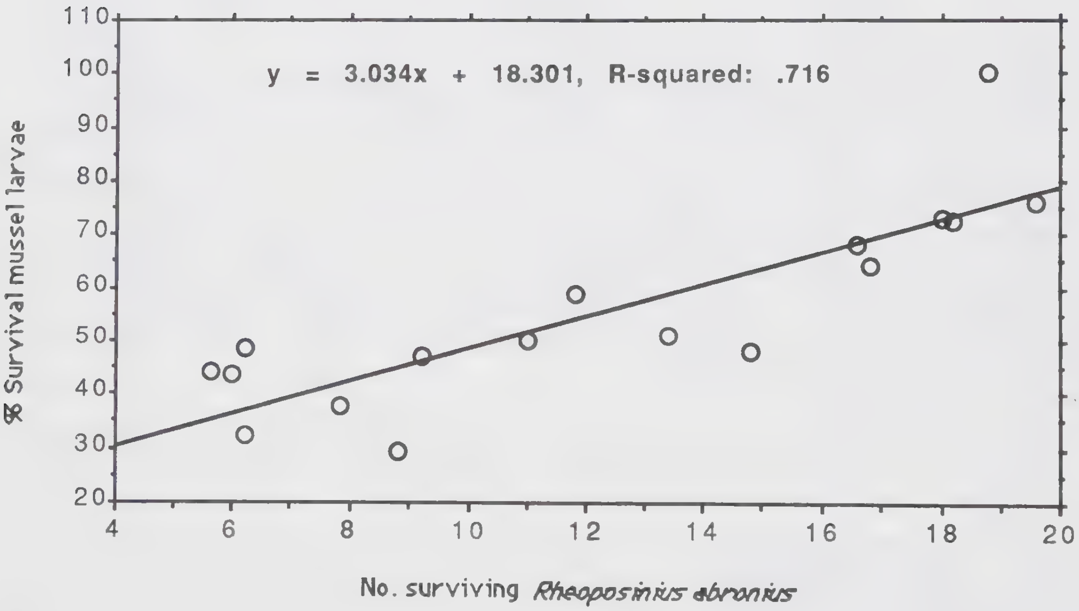
collected from 14 stations in the project area, and from control sites off Point Reyes and near Sequim Bay, Washington. Core samples were taken, and sediments from various depths in the cores combined to be representative of disposed material. The sediments were subjected to both biological and chemical testing. Solid phase bioassays were conducted with four species of organisms: the clam, *Macoma nasuta*; the polychaete *Nephthys caecoides*; and the amphipods *Rhepoxinius abronius* and *Grandidierella japonica*. Suspended phase bioassays were conducted with three species: the mysid *Acanthomysis sculpta*, the speckled sanddab *Citharichthys stigmaeus,* and larvae of the oyster, *Crassostrea gigas*. A large suite of metals and organic compounds was also analyzed in the sediments.

In the solid-phase bioassays, there were no statistically significant differences in survival between the controls and the 20 treatments for three of the four species. Significant effects were seen in the solid-phase bioassays for survival of *Rhepoxinius abronius* between sediments from control stations and four stations in Oakland Inner Harbor. In the suspended-particulate bioassays, there were small but significant depressions in the number of survivors of *Acanthomysis sculpta* and *C. stigmaeus* exposed to the harbor sediments relative to those from the control areas. There were significantly fewer survivors and greater abnormalities in oyster larvae exposed to three Oakland harbor sediments relative to those from control areas. The clam *M. nasuta* was analyzed for a variety of chemicals in its tissues. There were significant elevations of lead in tissues of this species relative to controls for two harbor sediments. For chromium, there was one harbor sediment treatment for which there was a significant elevation in clam tissue.

In a NOAA-sponsored study that employed multiple bioassays and endpoints, sediments were compared from Oakland Inner Harbor, near Yerba Buena Island, near Vallejo, from San Pablo Bay, and from Tomales Bay (Long *et al.*, unpublished). All sites showed significantly reduced survival of *Rhepoxinius abronius* relative to the control from the state of Washington, even those from Tomales Bay, a site selected for its low levels of anthropogenic disturbance. If the control from the State of Washington were to be eliminated, then only two areas with significant differences in amphipod mortality appear in pairwise comparisons of sites: there were more mortalities in Tomales Bay and Oakland sediments than there were in San Pablo Bay sediments (one-way ANOVA with Fisher's multiple comparison test). Mussel larvae bioassays with sediment elutriates showed similar results to those of the amphipod bioassays, with Oakland and Tomales bays having the lowest survival. In fact, the results of the two assays are closely correlated (Fig. 31), a relationship that has also been noted in data from Puget Sound (Williams *et al.*, 1986; Chapman *et al.*, 1987).

To help interpret the causes of toxicity, the sediment samples were also analyzed for a variety of trace metals and organic contaminants. Grain size and total organic carbon analyses were also carried out. These analyses showed that the Oakland samples had the highest concentrations of the trace metals silver, cadmium, copper, mercury, lead, and zinc. Similarly, ΣPAH, ΣDDT, and ΣPCB were also highest in the Oakland samples. Oakland and Tomales Bay samples also had the highest percentages of clay and the highest TOC concentrations. *Rhepoxinius abronius* survival and mussel larvae survival and abnormalities were not correlated with any of

Fig. 31. Relationship between the results of amphipod and mussel larvae bioassays using sediments from San Francisco and Tomales Bays (After Long *et al.*, unpublished).



the measured chemical parameters, but were significantly correlated with TOC concentrations (Fig. 32) and percent clay.

It is possible that these two bioassays did not primarily measure the toxicity of contaminants in sediments from the Bay-Delta, but rather tested whether the organisms were sensitive to high-organic-content, small-grain-size sediments. Such relationships have been shown previously for *Rhepoxinius abronius* (DeWitt *et al.*, 1988). This interpretation would also be consistent with empirical data that indicated poor survival in the fine-grained sediments from Tomales Bay, which for the most part had low concentrations of the measured contaminants. Since alterative interpretations of bioassay data are possible, caution is warranted in using sediment bioassays, alone, to evaluate toxicity of anthropogenic chemicals in the complex physical and chemical environment of estuarine sediments. More work is needed to develop or verify bioassays intended for use in predicting sediment toxicities in Bay organisms.

4. The Toxicity of Remobilized Contaminants

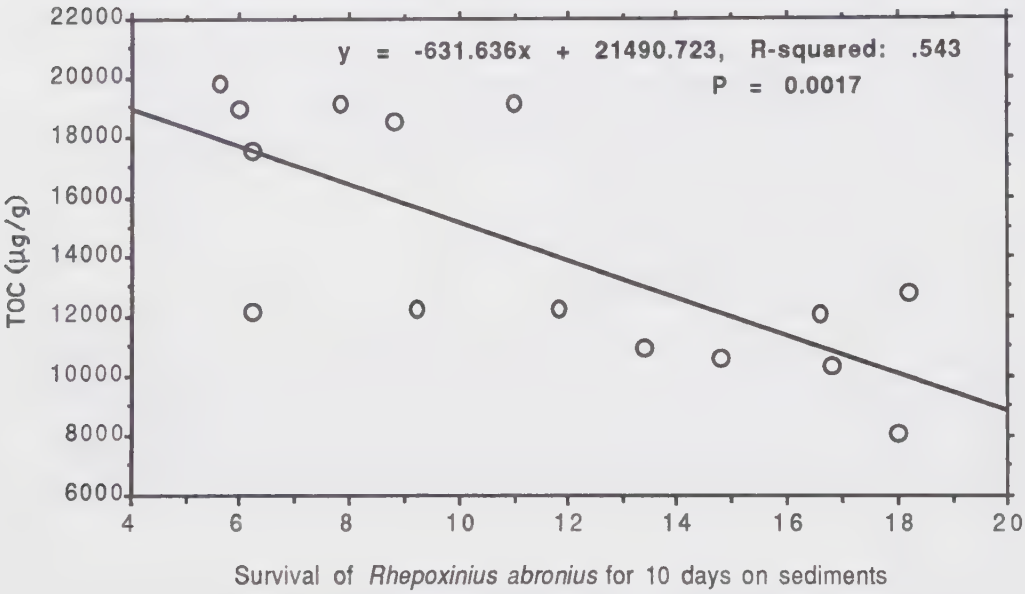
A. TYPES OF EFFECTS IN ORGANISMS

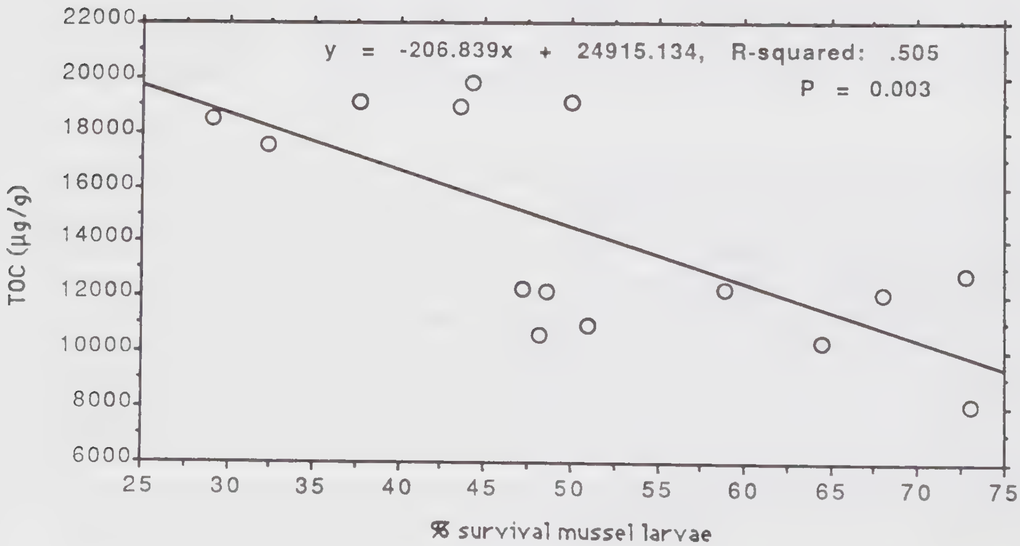
Contaminant effects on aquatic biota fall into two categories: acute effects and chronic effects. Acute effects are those that occur in the short term (hours to days) and are the result of brief exposure to high concentrations of contaminants. In current testing jargon, "acute" effects are those that occur, or can be measured, in the course of a 96-hr bioassay (see Section V.E., below). Acute effects are typically measured as mortality, narcosis, or some other "catastrophic" event.

Chronic effects are those that occur over an extended period of time (days to weeks) and are the result of prolonged exposure to concentrations of contaminants lower than those concentrations that cause acute effects. Chronic effects are typically measured as alterations in some critical physiological function, immune competence, reproductive success, enzyme induction, respiration, swimming ability, behavior, or the like. Chronic effects can include mortality; however, most bioassays aimed at detecting chronic effects are designed to measure endpoints that are manifest well before the onset of mortality.

The presence or absence of immediate mortality due to contaminant exposure is not a valid measure of the severity of the effect; it is not necessarily better for an organism to suffer chronic effects rather than acute effects from contaminant exposure. If contaminants were to result in a reduced ability of an organism to fend off disease (e.g., immunologic dysfunction), the affected population would become, in effect, ecologically dead; members of the population may survive for some period of time, but their susceptibility to the disease, and their ultimate death, would be as real as if each individual had succumbed in 96 hr to the acute effects of the same contaminant. What is critical with regard to the distinction of "chronic" *vs.* "acute" effects is that an individual or population suffering chronic effects of contaminant exposure has the potential to recover from those effects, providing the contaminant exposure can be removed.

<u>Fig. 32</u>. Relationships between a) total organic carbon and survival of *Rhepoxinius abronius*; and b) total organic carbon and survival of mussel larvae in sediment bioassays carried out with San Francisco Bay sediments. After Long *et al.* (unpublished).





The most common acute effect of contaminants on the biota is mortality; the acute LC-50 is an end point that measures the concentration of a contaminant that causes mortality in 50% of a population of test organisms within a 96-hr time period. Another expression is the LD-50, an expression describing the actual dose (rather than concentration) of a contaminant that causes mortality in 50% of a test population.

The mechanisms leading to acute and chronic effects of contaminants on aquatic biota are fundamentally different. Perhaps most important is that chronic effects of contaminants on aquatic biota require that the contaminant be accumulated from the environment and assimilated into tissues in concentrations great enough to alter some critical function. Acute effects do not require that the contaminant be accumulated or assimilated by the organism; many acute effects of contaminants on aquatic biota occur with little or no accumulation and are the result of rapid and severe disruption of the function of respiratory epithelia. The acute effects of most toxic metals on fishes, for example, are the result of mucous clogging and edema of the gills followed by a loss of oxygen exchange capacity. The acute, lethal effects of suspended sediments on fish gill are due either to "shredding" of the gill epithelium (in the case of angular, mineral solids; Rogers, 1969) or clogging of the respiratory passages followed by anoxia (O'Connor *et al.,* 1976).

Most problems of exposure of aquatic biota to chemical contaminants fall into the chronic effects category; even in such highly contaminated systems as New Bedford Harbor, the Hudson River, Waukegan Harbor and Commencement Bay, aquatic biota seldom respond to chemical contamination with mass mortality. Rather, the biota accumulate high concentrations of chemical contaminants and subsequently may be eliminated by disease, inability to escape predation, decreased reproductive capacity, or some combination of these or other sub-lethal effects. Data from the San Francisco Estuary show that the biota have accumulated measurable concentrations of a wide variety of contaminants (Long *et al.,* 1988; Luoma and Phillips, 1988; Phillips and Spies, 1988). Instances of acute lethality (i.e., fish kills) are rare, although observation and catch data from fishermen suggest a decline in fisheries productivity (see section V.D.6. below). Taken together, these data suggest that if contaminants are affecting finfish and shellfish productivity in the Estuary, such effects are more likely due to chronic, sublethal effects than to acute effects (Spies and Rice, 1988; Spies *et al.,* 1988). The fact that contaminants from dredged material disposal can be accumulated by aquatic biota (Anderlini *et al.,* 1975a,b; Rubinstein *et al.,* 1983; Lake *et al.,* 1985; O'Connor and Pizza, 1987; Gentile *et al.,* 1988) suggests that data on chronic effects of chemical contamination be examined very carefully, with an eye toward identifying appropriate endpoints for future study in the biota of the San Francisco Estuary. The remainder of this section reviews the data from research on sub-lethal and chronic effects studies conducted in the San Francisco Estuary and contiguous waters, as well as data from studies conducted in other systems where contamination problems similar to those in the San Francisco Estuary exist.

B. METALS

1. Sites of Accumulation and Target Tissues

Metals accumulation by aquatic biota is primarily *via* the ingestion of metal-contaminated food (prey or particulate matter). Assimilation into the tissues is determined by the efficiency of cross-gut transfer. Cross-gut transfer of many metals is quite low in aquatic biota (5 - 25% of the mass ingested) resulting in low bioaccumulation factors relative to sediment or food metals concentrations (O'Connor and Rachlin, 1982; Koepp *et al.,* 1987; Hodson, 1988). Fishes and invertebrates tend to concentrate many metals in liver and kidney tissue (or their functional equivalent). The metals with the greatest potential toxicity (Hg, Cu, Cd, Zn, Ag) tend also to stimulate the synthesis of metal-binding proteins (e.g., metallothionein) that can effectively remove metals from transport within the body of the organism (Jennings *et al.,* 1979; O'Connor and Rachlin, 1982; Hodson, 1988). Metallothionein synthesis and metal-binding also leads to slower elimination of metals. All classes of biota have been identified as having the potential to synthesize metallothionein, which has been proposed by Vallee (1979) as having a role in the detoxification of metals in organisms.

Many metals (Cu, Zn, K, Fe, Na) are essential to normal biochemical function; aquatic biota are therefore capable of regulating these metals, as well as similar elements that are considered non-essential (e.g., Cd, Pb, Hg; O'Connor and Rachlin, 1982). Metals that are combined with organic ligands (e.g., methyl- or dimethylmercury [MeHg], tributyltin [TBT]) are accumulated as organic compounds. Organic metals from biogenic processes (e.g., Cd-metallothionein, Cu-metallothionein) are also accumulated as organic compounds in food-chain transport processes.

2. Potential Chronic Effects

The major chronic "effect" of metals in most aquatic systems is the accumulation of metallic compounds and an increase in the mass transported to the next step in the food chain. Thus, clams, worms, and smaller crustaceans may incorporate metals into liver and kidney tissue where they are bound to metallothioneins and accumulate to high concentrations, and may then be accumulated by a predator.

Other potential chronic effects of metals include interference with respiration, kidney failure, alterations in osmoregulatory capacity, altered biochemical function and suppression (or elevation) of the immune response (Calabrese *et al.*, 1982; Hodson, 1988; O'Connor and Huggett, 1988). Some metals (Cr, Ni) are proven carcinogens in mammals, but this effect has not been tested in aquatic biota.

3. Relevant Studies

Several studies have indicated that metals-induced stress may be related to chronic effects on the biota of the Estuary. Johansson *et al.* (1986) showed a shift in intracellular protein distribution of Cd and Ag in *Macoma balthica* when metals concentrations were highest. Whether this effect has negative implications for the organism is not known. Other studies (Sanders and Jenkins, 1984) have shown

similar changes in distribution of metals associated with normal changes in physiological function.

Nichols and Thompson (1985a) showed that production of biomass by *M. balthica* was lower during periods of increased abundance of Ag and Cu. In fact, the population disappeared in 1978, when concentrations of both metals were most severe at Palo Alto. Such an effect, if due to metals contamination, may be related to the implication stated by Calabrese *et al.* (1982) that "...metal-induced stress may render the animal more susceptible to...environmental factors such as salinity, temperature, or disease."

The full range of chronic effects on aquatic biota due to Cd, Ag, and Hg contamination has been summarized by Calabrese *et al.* (1982). These include enzyme induction, depressed (and elevated) oxygen consumption, histopathologic lesions and increased sensitivity to organic contaminants. However, the summary by Calabrese *et al.* (1982) also lists an equal number of "no effects" results for exposure to metals in water. Furthermore, recent studies have shown the ability of aquatic biota to adapt or acclimate to high concentrations of metals such as Hg (Weis *et al.*, 1987) and Cd (Levinton, State University of New York Stony Brook, personal communication) either through increased metallothionein production or by selective processes. Clearly, our understanding of the extent to which exposure of aquatic biota to metals in the San Francisco Estuary impacts individuals and populations is severely limited. Stress and alterations of benthic communities that are apparently due to metals effects are evident in localities in the Estuary that are extremely contaminated (Luoma and Phillips, 1988). But the system-wide impacts of elevated trace elements are unclear, and, as stated by Luoma and Phillips (1988) "...establishing cause and effect will be particularly challenging."

Accumulation of metals released after disposal of dredged material in the San Francisco Estuary is possible, but may not occur to very high concentrations. Several studies examined the potential for mussels and other marine biota to accumulate metals in the vicinity of dredged material disposal operations, and all were positive, at least for some metals. Koepp *et al.* (1987) transplanted *Mytilus edulis* to sites near the Mud Dump in New York Bight and reported accumulation of Hg during disposal operations. However, neither Cd nor Pb accumulated to concentrations greater than in mussels placed at control sites. Lake *et al.* (1985) exposed mussels to Black Rock Harbor sediments in suspension in the laboratory and reported bioconcentration factors of from about 1,000 to 2,000 for Cr, Fe, Cu, and Pb; bioconcentration factors for Zn and Cd were about 6,500. However, in a subsequent report, Lake *et al.* (1987) stated that there was no relationship between laboratory results and field bioaccumulation of trace metals in mussels or in the polychaete *Nephtys incisa*. Only Cu accumulation occurred in field-exposed mussels; other metals accumulated to levels no greater than two times the concentrations seen at control stations. O'Connor and Squibb (1988) reported essentially similar data for mussels exposed to metals-contaminated suspended sediments in the lab; bioaccumulation after a 96-hr exposure was less than two times the value of lab controls, and other species (striped bass, blue crabs) did not accumulate Cd from suspended material.

Accurate predictions of metal accumulation from dredged material disposal in the San Francisco Estuary cannot be made from available model systems (e.g., partitioning or the Triad approach; see Chapman, 1984; Pavlou, 1984; Spies, 1989). In the absence of suitable models, accurate assessments of the impact of dredged material disposal on the potential for metal accumulation in the biota of the Estuary will, it appears, have to be based upon empirical data from extensive sampling.

C. ORGANIC CONTAMINANTS

1. Sites of Accumulation and Target Tissues

Accumulation of organic contaminants of concern in the San Francisco Estuary is primarily *via* the food chain; i.e., the ingestion of contaminated prey or, in the case of filter feeders and deposit feeders, contaminated particulate matter. Studies in other systems have shown that, at the levels of contamination present in the San Francisco Estuary, between 50 and 90% of sparingly soluble, lipophilic pollutants like PCBs, DDT, and PAHs in fishes will be derived from the consumption of contaminated prey (Thomann and Connolly, 1982; O'Connor and Pizza, 1987). Cross-gut transfer of PCBs, DDT, and PAHs is highly efficient (75 to 95% of the mass ingested; Pizza and O'Connor, 1983; O'Connor *et al.*, 1988). Therefore, exposure to relatively low doses of organic contaminants in the food may result in significant bioaccumulation. No attempt has been made to apply existing food-chain models (Thomann and Connolly, 1982; Connolly and Pedersen, 1987) of organic contaminant uptake to the finfish or shellfish populations of the Estuary. Nonetheless, it can be stated with some certainty that body burdens of the more persistent organic contaminants (PCBs, DDT, etc) in fishes will be dependent upon the mass of the pollutant material in food organisms and the frequency of feeding (Thomann and Connolly, 1982; Pizza and O'Connor, 1983; O'Connor, 1984). Fishes consuming diets low in contaminants will have lower body burdens than those feeding upon highly contaminated prey (Fisher *et al.*, 1983; Rubinstein *et al.*, 1983).

Body burdens of PAHs in fishes and crustacean shellfishes of the Estuary will, in all likelihood, be low; this is due to the fact that most PAH are metabolized rapidly by finfish and crustacean shellfish (Lee *et al.*, 1976; Moese and O'Connor, 1985; Stein *et al.*, 1987). Metabolic products of PAH metabolism may accumulate in the tissues of aquatic biota, however (Varanasi and Gmur, 1980; Moese and O'Connor, 1985), and measurement of PAH metabolites may serve as an excellent indicator of past exposure (Krahn *et al.*, 1984; Moese and O'Connor, 1985; Spies *et al.*, 1988).

PCBs, DDT, and other persistent compounds tend to accumulate in liver tissue and in lipid-rich tissues of aquatic biota. Parent PAH compounds do not accumulate in finfish and crustacean shellfish, but will accumulate in molluscs. Thus, molluscs are an important tool to be used in biomonitoring. Data on PCB, DDT, and toxaphene concentrations in striped bass, starry flounder, and white croaker from the Estuary show the highest concentrations of these compounds in liver and ovaries (Whipple, 1984; Crosby *et al.*, 1986), while Dungeness crabs accumulate the greatest concentrations of PCBs and DDT in the hepatopancreas (Haughen, 1983; Wild and Tasto, 1983). The liver of fishes and the hepatopancreas of crustacean shellfishes have the capacity to metabolize some organic contaminants (Malins *et al.*, 1988;

O'Connor *et al.,* 1988; Spies *et al.,* 1988), particularly some of the lower-chlorinated PCBs, the PAHs (including benzo[a]pyrene and dimethylbenz[a]anthracene) and other classes of organic contaminants. Bivalve molluscs (mussels, clams, etc.) have only a limited ability to metabolize organic contaminants (Livingstone and Farrar, 1985).

The primary target tissues for chronic effects of organic contaminants are the liver (or equivalent tissues) and gonads (Baumann and Harshbarger, 1985; Mix, 1986; Bailey and Hendricks, 1988; Malins *et al.,* 1988; Spies and Rice, 1988; Spies *et al.,* 1988). Most studies of organic contaminant distribution and disposition in fishes and shellfishes also show that the chlorinated organic classes (PCBs, DDT, dieldrin, etc.) also accumulate to high levels in brain and nervous tissue, but evidence for effects on nervous function in aquatic biota is lacking.

2. Potential Effects of Organic Contaminants

The ability to metabolize synthetic organic contaminants is well-developed in all classes of aquatic biota except the molluscs. This metabolic potential probably derives from the need for the biota to synthesize and degrade complex natural compounds such as steroids (Nelson *et al.,* 1987). However, as pointed out by Malins and co-workers (Malins *et al.,* 1988), the products of the metabolism of synthetic organic compounds in aquatic biota include intermediate metabolites that may have negative effects, such as the induction of tumor growth (Varanasi and Gmur, 1980; Mix, 1985; Bailey and Hendricks, 1988) and altered growth and reproductive patterns (Mehrle *et al.,* 1982; Spies *et al.,* 1985; Spies and Rice, 1988). The transformation of organic contaminants to biologically active intermediates appears to be of such importance that most investigators now consider induction of the mixed function oxidase system (MFO) to be an indicator of effect (Spies *et al.,* 1988).

Polychlorinated Biphenyls: Despite the vast amount of research on the topic, the real effects of PCBs on aquatic biota remain unclear. While certain PCB congeners have the potential to induce MFO activity to high levels, and while any number of negative impacts have been attributed to PCBs in the biota, some question remains as to the cause/effect relationship between PCB accumulation and specific chronic effects. In certain cases PCBs have been shown to have positive effects; for example, Bailey *et al.* (1984) have documented a cancer-protective role for PCBs when administered to fish in conjunction with the potent carcinogen *aflatoxin B1.*

The PCBs have been suggested as playing a role in tumorogenesis in Atlantic tomcod populations (Smith *et al.,* 1979), causing abnormal development of the vertebral column in Hudson River striped bass (Mehrle *et al.,* 1982), contributing to finrot disease in flatfishes on the Atlantic and Pacific coasts (Sherwood, 1982; Murchelano, 1982), and affecting the reproductive success of several marine fish species, including Baltic flounder (*Platichthys flesus*; Von Westernhagen *et al.,* 1981), Atlantic herring (*Clupea harengus*; Hansen *et al.,* 1985), and starry flounder (*Platichthys stellatus*; Spies and Rice, 1988). In virtually all the cases cited above exposure of the fish to environmental contaminants was not restricted to PCBs alone. It is difficult to conclude, therefore, whether PCBs played a causal role in any of the effects. In fact, PCBs may play a protective role. It has been noted by Bailey *et al.* (1984) and by Stein *et al.* (1987) that exposure of fishes to PCBs in combination with

carcinogenic compounds like benzo(a)pyrene or aflatoxin B1 may result in subtle changes in metabolism that lead to a reduced tumor incidence among exposed fish.

DDT and its Metabolites: Like the PCBs, DDT and its metabolites are highly persistent in environmental samples and are accumulated in the lipid stores of aquatic biota. Unlike the PCBs, parent compound DDT (p,p'-DDT) is readily metabolized in environmental samples; anaerobic metabolism of DDT yields p,p'-DDE, while aerobic metabolism yields DDD. Vertebrate organisms have the capacity to metabolize DDT via the enzyme DDT-dehydrochlorinase.

Chronic effects of DDT in aquatic systems have been identified as alteration of thyroid metabolism in fishes (Moriarty, 1975) and the induction of a number of enzyme abnormalities, including the enzyme carbonic anhydrase. It is possible that the major environmental impact of DDT has been to cause dysfunction of the carbonic anhydrase system, thereby leading to eggshell thinning in birds and reduced survivability in eggs and larvae of a number of aquatic species, including oysters (Moriarty, 1975). Valentine and Soule (1973) showed a statistical relationship between DDT in grunion eggs and fin-ray asymmetry, presumably due to the effects of DDT on carbonic anhydrase.

Many studies in mammals have shown DDT to induce tumors and other pathologies, including leukemia. There are no data on this subject in the fish literature; however, numerous authors have attempted to establish a relationship between DDT (and other chlorinated hydrocarbons) in sediments and epidermal disease incidence in marine and estuarine fishes (Sherwood, 1982).

Polycyclic Aromatic Hydrocarbons: Unlike the PCBs and DDT, the PAHs have been shown to have direct, sublethal impacts upon aquatic biota. First, the PAH (and associate petroleum hydrocarbons) induce high levels of mixed function oxidase activity that lead to the production of biologically reactive metabolites (Varanasi and Gmur, 1980; Stein *et al.*, 1987). Second, metabolism of the PAHs does not necessarily lead to their elimination; studies by Moese and O'Connor (1985), Moese (1988), and O'Connor *et al.* (1988) show quite conclusively that metabolites of three-ring (phenanthrene) and six-ring (benzo(a)pyrene) PAH accumulate in liver tissues of fishes and crustacean shellfish. Such accumulation of metabolites may lead to the formation of metabolite-DNA adducts and, possibly, carcinogenesis in fishes. Third, and most important, PAHs (benzo(a)pyrene in particular) cause liver cancer in fishes (Hendricks *et al.*, 1984; Bailey and Hendricks, 1988).

In addition to the direct evidence for the chronic effects cited above, field studies have implicated the PAHs in a number of incidences of disease among populations of marine and estuarine fish. Malins *et al.* (1988) showed that in Puget Sound the incidence of liver abnormalities in English sole was most closely correlated with the concentration of PAH in the sediments. Similar data exist for Boston Harbor, Massachusetts, and for the Southern Branch of the Elizabeth River, Virginia (O'Connor and Huggett, 1988).

3. Relevant Studies

Polychlorinated Biphenyls: PCBs are accumulated by aquatic biota from deposited and suspended sediments. Rubinstein *et al.* (1983) showed that the worm *Nereis virens* accumulated PCBs from New York Harbor sediments in a manner that was inversely related to the organic carbon content of the sediment in question. Thus, worms in sediments with low organic carbon accumulated more PCB than those in sediments with a higher organic carbon. Rubinstein *et al.* (1984) and Stein *et al.* (1984, 1987) showed that estuarine fishes (spot and English sole, respectively) accumulated PCBs from contaminated deposits, but that direct accumulation was relatively low; the majority of PCB accumulation seen in the field would probably be due to food-chain transport.

McFarland *et al.* (1986) tested the accumulation of PCB congeners from suspensions of contaminated dredged material. They showed that fathead minnows (*Pimephales promelas*) accumulated PCB congeners from suspended sediments in proportion to the solubility and log-octanol-water partition coefficient of the individual congeners.

Starry flounder, striped bass and white croaker from the Estuary have higher concentrations of PCBs than the same species taken at "clean" sites (Crosby *et al.*, 1986; NOAA, 1987; Long *et al.*, 1988; Spies and Rice, 1988). Mussels and clams from the Estuary also contain elevated concentrations of PCBs, presumably due to incorporation with particulate matter filtered from the water column (Phillips and Spies, 1988). Whether any of these elevated concentrations can be attributed to dredging and the disposal of dredged material cannot be stated at present. However, since laboratory studies have shown that suspended particulate matter can add to the body burden of PCB in fathead minnow (McFarland *et al.*, 1986), the possibility cannot be denied. Similarly, since PCB-contaminated dredged material may deposit and become colonized by fish-food organisms, and since fishes may consume these organisms and the PCBs, it is possible that dispersed, PCB-contaminated dredged material could be contributing to PCB burdens in the biota of the Estuary.

There are insufficient data available to ascertain whether the PCB burdens in fishes and invertebrates in the San Francisco Estuary could be the cause of chronic effects. Crosby *et al.* (1986) suggested that the concentrations of PCBs in striped bass in the Delta region of the Estuary "...might be sufficient to account for reproductive problems..." This conclusion must be viewed with some skepticism in light of the fact that striped bass from the Hudson estuary remain the only successfully reproducing population of the species in the nation, and do so bearing burdens of PCBs in the flesh, liver, and ovaries that are orders of magnitude greater than the concentrations of PCBs in striped bass from the San Francisco Estuary (O'Connor *et al.*, 1982; O'Connor and Huggett, 1988).

PCB-contaminated dredged materials are being disposed at dispersive sites in the Estuary. It is, therefore, very likely that some PCBs are being mobilized and made more bioavailable. It is likely also that the vast majority of PCBs associated with the disposed dredged material will remain adsorbed to the fine-grained particles and will be unavailable for accumulation, except by direct ingestion of the particles. Without the

application of numerical models of particle-PCB interactions and partitioning, it is presently impossible to estimate the proportion of PCBs on disposed dredged material that might be released or made bioavailable.

It is possible that filter feeders exposed to the elevated suspended solids loads from dredged material disposal could accumulate increased burdens of PCBs and serve as a vector for moving these PCBs into the food web of the Estuary. This phenomenon has been demonstrated by Lake *et al.* (1985, 1988) in studies of PCB accumulation in relation to dredged material disposal in Long Island Sound, and by Pruell *et al.* (1987) in their studies of PCB/PAH accumulation from suspended sediments. This possibility requires much additional study, particularly from the point of view of filter feeders as food resources in the Estuary, the range of transport of PCB-laden particles throughout the Estuary, and the extent to which PCB dose in the food might be increased for those species preying on filter-feeders and deposit feeders in the Estuary.

DDT and Metabolites: To our knowledge there are no data from the San Francisco Estuary as to the accumulation of DDT and its metabolites from dredged material. Data from transplanted and native mussel samples from the Estuary (see review in Phillips and Spies, 1988) show that these filter feeders can accumulate DDT from the water column, probably in particle-associated form. Thus, there is the possibility that DDT compounds, if released from disposed dredged material, might be available for incorporation in the food web of the Estuary, and for eventual accumulation in the fishes.

Both Long *et al.* (1988) and Phillips and Spies (1988) state that the data from the Estuary are too sporadic to allow an evaluation of the trend in DDT contamination in the Estuary. In the absence of significant DDT use in the drainage basin one would assume that DDT residues will, if anything, decline with time. Therefore, one would not expect to see increases in DDT burdens in either fish food organisms (as exemplified by mussels; from 200 to about 1000 ng g^{-1} dry wt.) or in fishes (100 to 200 ng g^{-1} wet wt.; approximately 400 to 1000 ng g^{-1} dry wt.) (Phillips and Spies, 1988). These data are similar to those reported by Stevens (1981) for striped bass from the San Joaquin River.

Polycyclic Aromatic Hydrocarbons: PAHs can be accumulated by aquatic biota from deposited sediments (Stein *et al.,* 1987; O'Connor and Squibb, 1988) and from suspended sedimentary material (Lake *et al.,* 1985, 1988; Pruell *et al.,* 1987). Fishes exposed to sediments containing benzo(a)pyrene accumulated low concentrations of this PAH (Stein *et al.,* 1987) over periods of time extending up to 30 days; most of the material was metabolized to compounds that were more polar than the parent compound. O'Connor and Squibb (1988) exposed striped bass to phenanthrene and fluoranthene in static test tanks and determined that the accumulation of both PAHs was rapid for the first 24 hr, but declined thereafter. Presumably the metabolism of both phenanthrene and fluoranthene was so rapid that the striped bass were eliminating the material as rapidly as it was assimilated from suspended particles.

Lake *et al.* (1985) studied the accumulation of PAH (and other compounds) by mussels and worms exposed to dredged material from Black Rock Harbor, CT. They determined that mussels accumulated PAH from the slurried sediment to concentrations between 100 and 1000 times the original concentration in the tissues. Bioaccumulation factors calculated for the mussels were (Log BAF) from 3.7 to 4.7.

Studies of PAH distribution and accumulation in the San Francisco Estuary are limited. PAHs in resident mussels from the Estuary were determined by Boehm *et al.* (1987) to range from 0.8 to 1.8 $\mu g\ g^{-1}$ (dry wt.) at two stations in the South Bay. Spies *et al.* (1985) reported PAH (and metabolite) concentration in starry flounder to be between 0.1 and 14 $\mu g\ g^{-1}$ (wet wt.) in the Central Bay and San Pablo Bay. The highest concentrations reported in starry flounder were from the Alameda Naval Air Station. Similar data were reported by Whipple *et al.* (1983) for striped bass from the San Joaquin (0.3 $\mu g\ g^{-1}$ wet wt.) and the Sacramento (2.3 $\mu g\ g^{-1}$ wet wt.) rivers.

Disposal of PAH-contaminated dredged material at dispersive sites in the Estuary will almost certainly cause increased availability of PAH to filter feeding and deposit-feeding biota. These organisms may then serve as vectors to transport the PAH into the food web of the Estuary. However, the same situation probably exists now, with wind- and tide-driven currents and turbulence serving to resuspend PAH contaminated materials in the shoal regions of the Estuary. Although the data are few, PAH concentrations in the biota of the Estuary are low. But it must be remembered (Krahn *et al.*, 1984; Spies *et al.*, 1988) that PAHs are rapidly metabolized by fishes and invertebrate shellfishes, and analyses for parent compounds have a high probability of yielding low values. This problem of analysis can perhaps be solved as Krahn *et al.* (1984) did, searching for evidence of PAH by analyzing for PAH metabolites.

D. SUMMARY

The contaminants that may be released or mobilized by dredging and dredged material disposal may be accumulated by the biota either directly from the water or through the food chain. Studies in a variety of ecosystems suggest that the most likely route for contaminant accumulation is via the food chain. Models for food chain transport of organic contaminants are rather well developed, while models for the accumulation of metals are less well developed.

The bioavailability of contaminants depends upon the physical state of the contaminant, and the way in which the organisms are exposed to the contaminant. Most metallic and organic contaminants associated with dredged material will remain associated with particles, especially when the sediment is composed of fine particles and contains a significant amount of organic matter. Under such circumstances, organic contaminants will not be readily bioavailable unless ingested. Particle-bound metallic and organic contaminants are available to filter feeders and deposit feeders; consequently, they may be available to the organisms that prey upon them. However, there is no evidence that "biomagnification," a step-wise increase in contaminant accumulation with increasing trophic levels, is occurring in the San Francisco Estuary due dredging and dredged material disposal.

Metals and the organic contaminants of concern can have lethal and sublethal effects on aquatic biota. Few if any instances of acute effects have been observed in the San Francisco Estuary. If effects are to be observed in the Estuary, their manifestation will probably be as long-term, or chronic, effects. Few adequate assays for chronic effects of organic or metals contamination exist for application in aquatic systems. Contaminant bioassays that have been applied to the San Francisco Estuary demand careful interpretation because they may, in fact, be assays for environmental effects related to, but quite different from, the effects of the contaminants in question.

Contaminants derived from dredged material may well be exerting a negative influence in the Estuary, although such a relationship remains to be proven or disproven. There are significant gaps in our knowledge of the effects of sediment-borne contaminants in aquatic biota. The development of appropriate assays, and their appropriate application to the Estuary, is an essential item for future research.

5. Increased Suspended Sediment Concentrations

Increased concentrations of suspended sediments are an unavoidable effect of dredging and disposal of dredged material. Under certain circumstances these increases have the potential to cause adverse impacts on biological resources. This section examines suspended sediment plumes that result from dredging and disposal activities and the potential effects of elevated suspended sediment on estuarine biota.

Turbidity is a measure of the absorption of light by a solution and integrates the optical effects of all suspended particulate matter, including mineral solids, detrital material, phytoplankton, zooplankton, bacteria, and colloidal matter. There is no direct relationship between turbidity and suspended sediment concentrations, although sediment resuspension during dredging and disposal of dredged material causes increases in turbidity. During dredging, sediments are suspended by contact between the cutting device and bottom sediments, and by the overflow of barges and hoppers. The latter removes water containing suspended sediments from the barge or hopper to create a denser load, reducing transport costs. Sediments can also be released to receiving waters from the bucket of a clamshell dredge as it is lifted through the water column (USCOE, 1976b; Tavolaro, 1984).

USCOE (1976b) reported turbidity and suspended solids concentrations monitored during dredging operations conducted in San Francisco Bay using different types of equipment (a description of dredging equipment appears in Appendix 2). Measurements were taken before, during, and after dredging at two or three water depths at each of several stations down-current from the dredging site. When hopper dredges were used, suspended solid concentrations up to 2,500 mg L^{-1} could be found adjacent to the draghead in the lower water column. These concentrations decreased to less than 500 mg L^{-1} 100 m from the site. The overflow ports of the hopper released water with suspended solids concentration of 3,500 mg L^{-1}, but this concentration was reduced to less than 500 mg L^{-1} 50 m downstream from the dredge. When dredging and hopper overflow occurred simultaneously, suspended solids concentrations above background were observed up to 800 m downstream (USCOE, 1976b). Barnard (1978) reported elevated suspended sediment concentrations as much as 1,200 m down-current during a hopper dredging operation in Lake Huron.

A similar pattern has been observed during monitoring of clamshell dredging in Oakland Inner Harbor (Fig. 33). As no barge overflow occurred during this operation, the suspended sediment plume in the lower water column, at depths of 9 m, was much greater than at the surface. Similar results have been reported for other clamshell dredging operations (Barnard, 1978). Tramontano and Bohlen (1984) reported a concentration of suspended solids near the substrate of over 1,500 mg L^{-1} some 12 m from a clamshell dredging operation in the Thames River, New London, Connecticut. This very high concentration decreased to near-background 180 m down-current. Unlike hopper dredging, a clamshell dredge loses material as it is drawn up through the water column, and thus elevated suspended solid concentrations were also detected at intermediate depth (5 m; Fig. 33).

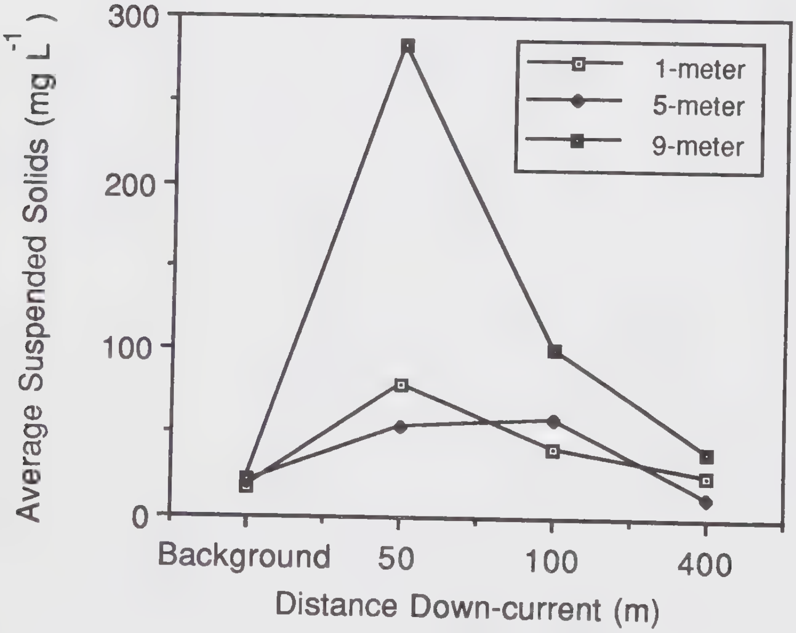
Although increases in suspended sediment concentrations from clamshell dredging are less than those from hopper dredging, comparisons are greatly influenced by the local hydrologic conditions, flocculation rates, the characteristics of the sediment being dredged, and barge overflow (USCOE, 1976b). Sediments of low density (i.e., those with higher moisture content) are more easily disturbed and mix with receiving waters more readily when moved. The manner in which a dredge is operated is also important, and operator training and performance can influence the generation of suspended sediment plumes (Barnard, 1978).

The aquatic disposal of dredged material has a major, though transient, impact on suspended sediment concentrations in the water column. Only a small amount of the disposed material, consisting of some of the fine fraction, remains in the upper water column at the disposal site. This pattern has been observed in several studies (Gordon, 1974; USCOE 1976b; Tavolaro, 1984; SAIC 1987b,c). Gordon (1974), in a study of the New Haven (CT) disposal site in Long Island Sound, determined that 99% of the material discharged during a disposal event descended to the substrate during the phase of convective descent; less than 1% of the material remained in the upper 13 m of the 18-m water column. The cloud of suspended sediment close to the substrate was initially about 4 m in height, and the turbidity (as measured by percent transmittance) at a fixed station 30 m down-current from the discharge point reached a maximum for a 5-minute period, commencing 3 minutes after the discharge. After 20 minutes, local turbidity values approached background.

Turbidity at the New Haven site was also monitored from a surface drifter. These data showed that the suspended sediment close to the substrate had spread 77 m from the disposal site in 14 minutes, gradually decreasing in thickness as it spread. The cloud of suspended sediment did not spread more than 100 m from the disposal site. Currents close to the substrate at this site were weak (1.2 cm sec^{-1}), and greater dispersion would be expected under a stronger current regime such as that in Central San Francisco Bay.

USCOE (1976b) monitored turbidity plumes during the disposal of dredged material after disposal at the Carquinez Strait and Alcatraz disposal sites. Vertical profiles were taken at sites 50 m, 100 m, and 400 m down-current from the impact area, and showed maximum turbidity (zero transmission) immediately after disposal in waters close to the substrate at the disposal sites. Surface waters were less turbid.

Fig. 33. Average concentrations of suspended sediments at different depths down-current from a clamshell dredge deepening a channel in the Oakland Inner Harbor. After USCOE (1976b).



Turbidity usually returned to background 10-15 minutes after disposal, with the upper water column clearing faster than deeper waters.

In special studies of disposal at the Carquinez Strait site (USCOE, 1976b), samples of suspended solids were collected from waters close to the substrate 50 - 100 m down-current from the dredge. High concentrations of suspended solids (up to 9,000 mg L^{-1}) were measured close to the substrate, but decreased to background after 25 minutes. Between 1% and 5% of the disposed material remained in the upper water column. An additional study collected samples at three depths from four down-current stations. This study demonstrated that maximum concentrations of suspended solids were up to 100 times higher (20,000 mg L^{-1}) in waters close to the substrate than in near-surface waters (200 mg L^{-1}), and that elevated suspended solids concentrations could occur as far as 1,400 m down-current. This phenomenon rarely lasted longer than 10 minutes.

Science Applications International Corporation (SAIC), under contract with the USCOE, monitored the disposal of sediments at the Alcatraz site. The sediments were dredged by clamshell from the San Rafael Channel (SAIC, 1987b) and by hopper dredge from the Richmond Channel (SAIC, 1987c). These studies included tracking the plume from 11 discrete disposal events on six different days during different tidal conditions (high and low slack water, moderate and maximum ebb and flood currents). Plume tracking was accomplished by measuring the acoustic backscatter (at 200 kHz) from the plume as the survey vessel transited the disposal area. Samples of suspended solids were taken at least twice during each disposal event to calibrate acoustic measurements. The results showed that the behavior of the plume was dictated by the tidal conditions at the time of disposal. Disposal at slack water resulted in plumes of suspended material that exhibited little lateral movement. Disposal at maximum ebb and flood resulted in plumes that migrated in the direction of the tide (east or west) at rates up to 140 cm sec^{-1}.

Concentrations of suspended solids in the lower water column, ranged from 44 to 165 mg L^{-1}. The plumes were tracked until they dissipated, which usually took from about 10 to 15 minutes. In one instance, suspended solids concentrations of 80 mg L^{-1} (four times the background value) persisted for up to 20 minutes after disposal. SAIC (1987b) attributed unusual event to disposal of a large quantity of material under conditions of high current velocity. This work was not conducted from a fixed sampling station, and thus the return of turbidity to background due to movement of the plume away from the monitor was unlikely.

The transient nature of these disposal-related suspended sediment plumes as measured by SAIC (1987b,c) contrasts with eye-witness accounts of fishermen, who report chronic turbidity in the Central Bay. The fishermen point out in particular that Central Bay is now turbid during times when "...its waters were historically blue instead of brown" (UAC, 1987b).

The apparent contradiction between SAIC (1987b,c) and eye-witness accounts of fishermen might be explained by the failure of sampling designs at the disposal site to take the frequency of disposal events into account. As discussed in Section V.A., there were many days during 1986 and 1987 when more than 20 disposal events

occurred. An average of more than 20 disposal events occurred each day during the months of February and March 1986 and September 1987 at the Alcatraz site (USCOE, 1989d). This was also probably true for April 1987, but data were not available. SAIC (1987b,c) conducted its surveys of discrete disposal events at a location distant from other disposal activity at Alcatraz, and no attention was given the potential cumulative impact on suspended sediment concentrations from several disposal events occurring in a short period of time. The results of SAIC (1987b,c) suggest that some accumulation of suspended sediment in the water column could occur if three or more disposal events were to occur during one hour (see below). Repeated disposal events could also increase the reservoir of sediments available for resuspension in the Central Bay, contributing to increased concentrations of suspended sediments in the water column.

To summarize, dredging and disposal operations inevitably increase the concentration of suspended sediments in waters close to the sites of operation. The extent to which this occurs is determined by the characteristics of the dredged sediment, local hydrology, and dredging and disposal techniques. Hopper dredges tend to produce greater concentrations of suspended sediment than clamshell dredges. Plumes of suspended sediment were sometimes being detected over 1,000 m down-current from hopper dredging operations. Increases in turbidity are more pronounced in the lower water column, where concentrations of suspended solids may range up to several grams per liter for 10-15 minute periods. Increases in local suspended sediment concentrations can be much greater during disposal than those observed during dredging, especially in the lower water column. Frequency of disposal is an additional factor that might influence the concentrations of suspended sediment near disposal sites.

Studies show that no more than 5% of the disposed material remains in the upper water column. Research at the Alcatraz disposal site demonstrates that plumes of suspended solids move in the direction of the tide. Even if disposal occurs during slack water, suspended sediment plumes almost always dissipated to background values within 20 minutes. This contrasts with the eye-witness accounts of fishermen that indicate extensive turbidity in the Central Bay. No attempt has yet been made to monitor suspended sediment plumes during periods of high use at disposal sites in the Estuary. It is possible that a significant increase in suspended sediment concentrations could occur in the water column of Central Bay if suspended sediment generated by successive disposal events accumulates. Heavy use of the disposal site could also increase the reservoir of material available for resuspension from disposal sites. The following Section examines the potential impact of increased suspended sediment concentrations on biota in the Estuary.

6. Effects of Increased Suspended Sediment Concentrations on Biota

The potential impacts of local increases in suspended sediment concentrations due to dredging and disposal operations in the San Francisco Estuary need to be considered in the context of the temporal and spatial variation of natural suspended sediment concentrations. USCOE (1975b, 1988a) cites the approximation of Krone (1966) that 160 million yd^3 (118 million m^3) of sediment was resuspended annually in the Estuary by the action of tides, waves, and wind. By comparison, the amounts of

material dredged and disposed of at aquatic sites in the Bay are relatively minor, being between 5 and 10 million yd^3 (3.8 and 7.6 million m^3) in most years.

Krone's (1966) approximation of sediment resuspension in the Estuary must be questioned for at least two reasons. First, it was based upon an assumed concentration of 500 mg L^{-1} sediment in Estuary waters of 1.5 m or less. This concentration could be excessively high; the data reviewed in preparation of this report showed that high average suspended sediment values in the Estuary were more on the order of 100 to 350 mg L^{-1}. If we assumed that waters of less than 1.5 m depth generated a suspended sediment concentration of 250 mg L^{-1}, rather than 500 mg L^{-1}, then the amount of sediment resuspended each year could be estimated at 80 million yd^3, (about 56 million m^3) rather than 160 million yd^3 (122 million m^3).

Second, in estimating resuspended sediment at 160 million yd^3 per year, it would appear that Krone (1966) underestimated the portion of the Estuary surface with depths of 5 ft or less. Back-calculating from Krone's (1966) results, it would appear that he estimated sediment resuspension from an area of about 294 km^2 (9% of the surface area of the Estuary. This area is probably too small; Nichols *et al.* (1986) stated that more than 40% of the Estuary's 3,255 km^2 of surface area is less than 2 m deep. If sediment resuspension as suggested by Krone (1966) were applied to a shoal region of about 1,050 km^2, then the amount of sediment resuspended per year could well be more than 600 million yd^3 (about 458 million m^3). Even when one applies a reduced resuspension concentration of about 250 mg L^{-1} to the expanded area (about 1,050 km^2), an estimated 286 million yd^3 (219 million m^3) per year of sediment would be resuspended in the Estuary due to natural forces.

Exactly how natural sediment resuspension and resuspended dredged material compare cannot be stated at this time. It is obvious from the foregoing discussion that assumptions can be manipulated to generate almost any value, high or low, that one might choose. This points out the critical need for empirical data, especially data on the amount of annual sediment resuspension due to natural forces, and the amount of disposed dredged material that remains suspended in the Estuary.

In addition to wind- and tide-driven resuspension, freshwater inflows at the Delta drive plumes of suspended sediments through the Estuary which dominate the turbidity of the system in times of high run-off. Carlson and McCulloch (1974) report the concentration of suspended solids in such plumes as almost 50 mg L^{-1}. This value is similar to concentrations of suspended solids measured in plumes generated during the initial dispersion of disposed sediments at the Alcatraz site (SAIC, 1987b,c). As described above, disposal events can occur frequently with relatively large quantities of sediment disposed in a short period of time. It is possible that elevated suspended sediment concentrations could affect the biological resources of the San Francisco Estuary adversely. The following sections discuss the available evidence on this aspect.

A. FISHERIES

Most investigators consider the turbidity increase associated with dredging and the dredged material disposal as transient and relatively unimportant (e.g., see Wright, 1978; SAIC 1987b,c; USCOE, 1988a; Engler and Mathis, 1989). However, concern exists at present regarding fishing success in Central Bay and dredge spoil disposal at the Alcatraz site (California Department of Fish & Game [CDFG], 1987; Citizens for a Better Environment [CBE], 1987; United Anglers of California [UAC], 1987a,b; Segar, 1988). This concern originated with observations by commercial fishermen that turbidity has apparently increased in the Central Bay due to the disposal of dredged material. The UAC have stated that observations by fishermen have "...verified that the dumping of spoils has turned the water to a turbid condition the color of mud over most of the main bay for prolonged periods of time" (UAC, 1987a, p. 3, emphasis original). UAC members report that the summertime turbidity from wind and waves, which used to drop during periods of low wind, no longer "breaks" in this fashion. There has been a significant drop in the number of recreational partyboats fishing in the Bay due to a lack of fishing success, and those operating must often leave the Bay in order to satisfy clients (J. Beuttler, UAC, personal communication).

One hypothesis put forward by the fishermen to explain the decline in fishing success is that increased suspended sediment concentrations in the water column force forage fish (e.g., smelt and anchovies) from the Central Bay. The reduced forage causes larger fish to leave the region in search of food. The UAC acknowledges that dredge disposal is only one of several possible explanations for reduced fishing success (J. Beuttler, UAC, personal communication). Other potential influences include freshwater inflow, temperature, overfishing, and fluctuations in the near-coastal marine environment.

Data collected by the CDFG on the success of recreational partyboat fishing appear to support the fishermen's observations. Catch per Unit Effort (CPUE; fish caught per angler hour) for 1985 in Central Bay declined by about 50% between 1980 and 1984, and remained low from 1986 to 1988 (SFBRWQCB, 1989a; D. Lollock, CDFG, personal communication). This apparent relation is emphasized by comparing disposal at Alcatraz from Civil Works and Navy maintenance operations (the only data available) for 1975-85 and 1986-87. The data (from Tables 5 and 8) show that the average disposal of 2.2 million $yd^3\ yr^{-1}$ (1.8 million m^3) in 1986-87 is a 14% increase over the 1.9 million $yd^3\ yr^{-1}$ (1.5 million m^3) during 1975-85.

The timing of the decline in the CPUE statistics may also correspond to the introduction of the slurrying requirement for dredged material disposal at Alcatraz. This requirement could increase the suspended sediment concentrations in this region by requiring disposal of sediments that are more easily entrained in the water column or eroded from the sediments. USCOE (1988a) state that the slurrying requirement did not begin until September, 1987, and, thus, could not have affected the decline in fishing success from 1980 to 1984 or the continued low fishing success in 1986 and the first eight months of 1987. USCOE (1988a) also states that the difficulty in producing slurried material from clamshell dredging operations resulted in little change in actual disposal operations.The CDFG, however, states that correspondence from the USCOE indicates that operators of clamshell dredges were concerned about

being able to implement a slurrying requirement in effect months before September 1987 (CDFG, 1989).

In response to these (and perhaps other) concerns relating to the impacts of dredging and disposal operations, the San Francisco Bay Regional Water Quality Control Board recently adopted new limits on the disposal of dredged material at sites within the Estuary (SFBRWQCB, 1989b). The Regional Board proposed these limits (Table 18) as a prudent action to lessen potential impacts upon fish, migration routes, or fish spawning habitat. During the recreational fishing season (May through September), the draft resolution proposes limiting the disposal of dredged material at the Alcatraz site (only) to 0.3 million yd^3 (0.2 million m^3) monthly, as compared to 1.0 million yd^3 (0.8 million m^3) monthly for the remainder of the year. In addition, the Draft Policy notes that the Regional Board may restrict:

"(a) dredging activities from December through February in selected sites along the waterfront where Pacific herring are known to spawn; and

(b) disposal activities at the Carquinez Strait site during spring and fall in order to protect striped bass and salmon migrations (SFBRWQCB, 1989b)."

SFBRWQCB (1989a) and USCOE (1988a) state that there are no adequate scientific data to support the contention that increased turbidity is influencing recreational fishing success in the Central Bay. It should be stated here (as in SFBRWQCB [1989a]) that existing information is also inadequate to refute this contention. Given the many factors that could influence fishing success in Central Bay, the unequivocal demonstration of a link between the disposal of dredged material and fishing success would be exceptionally challenging.

Several factors contribute to the inadequacy of the existing database regarding the impact of turbidity upon fishing success in Central Bay. There is no long-term turbidity database in the Central Bay that could be used to assess changes in turbidity. No correlation is evident between available data on CPUE and dredged material disposal in the region, although there are questions regarding the utility and completeness of the CPUE data. In addition, the available data suggest that tidal stage and runoff events rather than disposal events or erosion of sediments from the mound at Alcatraz appear generally to determine Central Bay turbidity (Winzler and Kelly, 1985; SAIC, 1987b,c). Finally, calculations of the potential for dredged material disposal to cause increased turbidity over long periods of time support the field measurements showing that the increase in turbidity due to dredged material disposal is a transient and localized phenomenon. As discussed previously, however, there has been no adequate examination of the potential impact of frequent disposal events upon the suspended sediment regime in the Central Bay. Each of these factors will be discussed below.

Very few measurements of turbidity or suspended sediment concentrations in the Central Bay waters are available. Routine monitoring data from CDFG (conducted as part of the Interagency Ecological Studies Program) consist of monthly estimates of surface water clarity using a Secchi disk at eight stations (USCOE, 1988a; SFBRWQCB, 1989a). The estimation of turbidity values from Secchi disk readings is

Table 18. Limits proposed by the San Francisco Bay Regional Water Quality Control Board on the volumes of dredged sediment disposed of at aquatic sites in the Bay (SFBRWQCB, 1989a).

Annual Limits (million yd^3)		
Alcatraz		4.0
San Pablo		0.5
Carquinez Strait		2.0
Suisun Bay Channel		0.2
Monthly Limits		
Alcatraz		
	October - April	1.0
	May - September	0.3
San Pablo Bay		
	All months	0.5
Carquinez Strait		
	All months	1.0

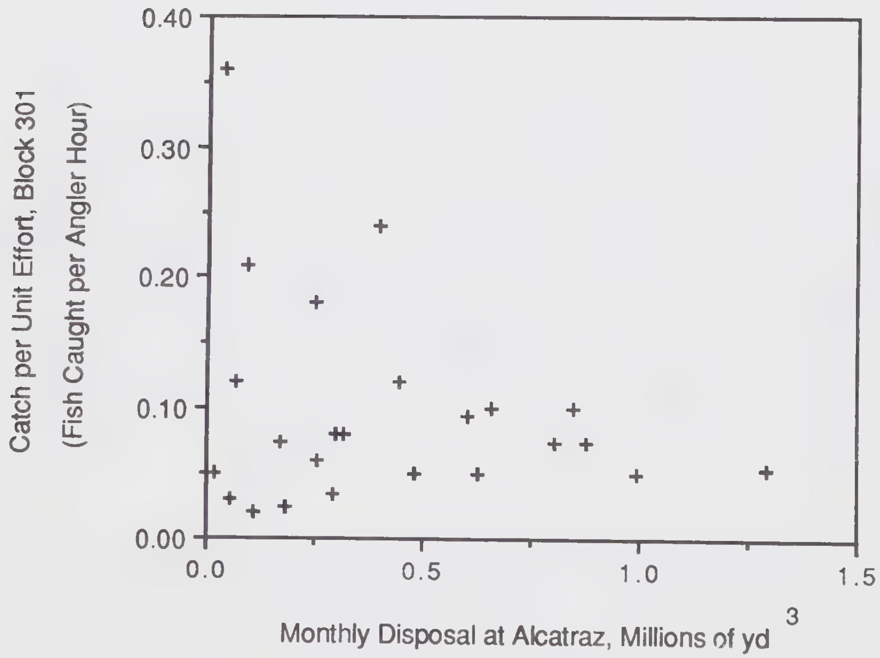
open to criticism, as conditions at the water surface (e.g., wind and sunlight) can affect Secchi disk values markedly. In addition, Secchi disk values only refer to water clarity in the upper layers of the water column and are a subjective determination by a human observer. Furthermore, it is unlikely that monthly sampling of turbidity in a high-energy tidal environment would be sensitive enough to ascertain increases in ambient turbidity. Additional data are required if meaningful correlations are to be sought between fishing success and factors affecting turbidity of the waters of the Estuary.

Records are available from 1986 and 1987 for the approximate monthly disposal of dredged material at the Alcatraz site. It is possible to use these to evaluate whether a correlation exists between CPUE and dredged material disposal. As shown in Fig. 34, a scatter plot indicates no relationship between fishing success and the monthly rates of disposal of dredged material at the Alcatraz site ($r^2 = 0.06$). Although these data suggest that fishing success is not related to monthly rates of disposal, the lack of a significant correlation does not prove that disposal of dredged material at Alcatraz has no impact upon fishing success. The lack of correlation may be due to inadequate data in any of several areas. For example, the correlation between dredged material disposal and fishing success may be a more complex relationship than presented here. It could be that frequency of disposal during a specific period of time, or a specific season, is the proper measurement for correlation with CPUE during summer months. Such a relationship should be investigated in the future as more data on dredged material disposal become available. In addition, partyboat fishing represents only 17% of the total local saltwater sport fishing (CDFG, 1987), and the data in Fig. 34 may not be valid assessment of fishing success in the Central Bay. As disposal events may not affect turbidity of the entire Central Bay, data for fishing success from specific portions of Central Bay (such as near the Alcatraz site) might demonstrate a more robust correlation with dredged material disposal.

In addition, CPUE statistics are normally applied to commercial fisheries in which the type of gear, fishing technique and location, and species taken are relatively consistent. When such statistics are applied in a recreational setting (varying skills of the fishermen, different gears, baits, etc.), significant variability can be expected. The efficiency of a given method of fishing for one population can also vary over time due to changes in feeding behavior as a given age-class grows. Consequently, many factors contribute to variations in CPUE statistics, confounding correlations drawn between these statistics and other data. Finally, using daily statistics for disposal and fishing success might demonstrate a correlation not clear from monthly averages.

Thus, there are not adequate data to prove or disprove whether dredged material disposal has increased turbidity in Central Bay and resulted in an adverse impact on fisheries. Other data are also inconclusive. The natural turbidity of receiving waters in the Alcatraz area is highly variable. Data gathered by Winzler and Kelly (1985) and SAIC (1987b,c) indicate that the concentrations of suspended sediments in this region correlate with tidal stage; concentrations of suspended sediment are highest near Alcatraz just after low water slack, when turbid water from the upper portions of the Estuary is drawn into Central Bay. Concentrations are lowest just after high water slack, when relatively clear ocean water has been transported into Central Bay. If the erosion and transport of sediments from the Alcatraz disposal site (or other

Fig. 34. Scatter plot of monthly disposal of dredged material at the Alcatraz site against Catch per Unit Effort for recreational partyboats (Block 301, Central Bay), over 1986 and 1987. Data for disposal from USCOE (1989a, 1989b); some monthly estimates are only approximate. Data for Catch per Unit Effort from SFBRWQCB (1989a).



locations) were controlling turbidity in Central Bay, maximum suspended sediment concentrations should be dependent upon current velocity, not tidal stage. Additional data regarding suspended sediment concentrations in Central Bay is needed to verify this relationship.

SAIC (1987b,c) presented a general calculation to evaluate whether the increase in suspended sediments in the water column just after a disposal event is significant. They assumed that 10% of a 4,000 m^3 disposal load, of density 1.3 g cm^3, remained in the upper water column after disposal. This may be conservative, as published data suggest that a figure of from 1 to 5% is more likely (Gordon, 1974; Tavolaro, 1984). SAIC (1987b,c) assumed that disposed material was dispersed over an area of 1 km^2 to a depth of 25 m. The calculated increase in the average concentration of suspended solids in this water volume was 0.02 mg L^{-1}, or between 0.1 and 0.2% of the ambient suspended solids load.

Upon reexamination, we determined that the SAIC calculation (1987b,c) was incorrect. Using the SAIC assumptions, and factoring in the necessary correction for solids content of the disposed dredged material (about 34%), the correct calculated value for the average additional suspended solids load from dredged material disposal should be about 8 mg L^{-1}. This concentration is an increase of from 50% to 80% of the long-term average for concentrations of suspended solids in Central Bay waters. The implication of this calculated value is that disposal of dredged material at Alcatraz could increase the ambient suspended solids concentrations in Central Bay by 50% for a measurable period of time over a localized area.

Dispersion of disposed dredge materials would, of course, continue beyond the water volume of 0.025 km^3 assumed by SAIC (1987b,c), creating further dilution of the plume of suspended sediment over time. The calculation of an increase of 50 to 80% over ambient suspended solids concentrations suggests that increases in the turbidity of Central Bay waters due to disposal of dredged material are a possibility, although they would be somewhat localized in time and space.

Since it is not uncommon for more than 20 disposal events to occur at Alcatraz each day, it is possible that increases in suspended sediments concentrations greater than that predicted by the above calculation could occur in the water column of Central Bay during periods of frequent disposal. A worst-case scenario can be calculated by assuming that 10% of the sediment (density of 1.3 g cm^3) contained in 41 barges (4,000 m^3 capacity) remains in the water column of western Central Bay (west of Angel Island, east of the Golden Gate). This is a "worst-case" in the sense that 1) 10% loss to the water column is as high as any measured value, and 2) 41 barges is the maximum one-day value from available records (1986 to 1987).

To make this assessment realistic, we must include a factor for the loss (or "decay") of the suspended sediment load due to the dilution and settling of sediments. This can be done using a decay function model to calculate the proportional accumulation over time in a situation where the water body is subjected to multiple "doses" (disposal events), each subject to independent decay In such a case,

$$X_n = X_o \frac{(1 - e^{-(ket^*n)})}{(1 - e^{-(ket^*)})}$$

where X_n is the concentration of substance accumulated (in this case, sediment in the water column) after n doses of concentration X_o each separated by t* minutes, with a first-order decay constant (or "loss" coefficient; assuming concentration-independent decay) of k_e (Goldstein *et al.*, 1974). For n = 41, a three-shift (24-hour day) dredging operation will result in a disposal frequency (t*) of about 35 minutes. Using data from the plume tracking studies of SAIC (1987b,c), one can use linear regression to estimate a decay constant of $k_e = 0.07451$ min^{-1}. If the disposed sediments mix throughout the western Central Bay to a depth of 15 m, it would add about 7 mg L^{-1} of suspended sediments to the water column. Such a modest value is calculated because the decay rate, which can be thought of as 7% each minute, is large relative to the dose rate of 35 minutes. This calculation suggests that frequent disposal would not have a significant effect upon the suspended sediment concentration in the western Central Bay. However, additional data would be desirable to verify the loss coefficient in this calculation.

Although disposal plumes may decay so rapidly that accumulation of sediment in the water column may not occur, effects could still occur on fish populations due to frequent disposal. If a disposal event occurs on average every 45 minutes (32 events per day), then fish in and around the disposal site would be exposed to elevated suspended sediment concentrations for several minutes each hour. If each event decayed to background in 15 minutes, then fish in the region of the disposal site would be exposed to elevated suspended sediment concentrations 33% of the time. This type of exposure could result in an effect (such as a behavioral change) even though there is no accumulation of sediment in the water column over time.

As part of the major study of dredging and disposal in the Bay conducted in the 1970s, the USCOE investigated the sensitivity of a variety of species from the San Francisco Estuary to suspended sediments (Peddicord *et al.*, 1975). Fish were exposed to suspended kaolin (an aluminum silicate clay mineral); test species included *Parophrys vetulus* (English sole) and *Cymatogaster aggregata* (shiner perch). No mortality was observed in specimens of *P. vetulus* held for 10 days at concentrations of 70,000 mg L^{-1}, although *C. aggregata* was much more sensitive, the 200-hr LC_{50} for San Francisco Bay specimens being 3,000 mg L^{-1}. Additional experiments using bentonite (another aluminum silicate) to simulate San Francisco Bay sediments indicated that survival of test organisms was reduced by lower temperatures and reduced dissolved oxygen. The mean survival time of *C. aggregata* exposed to 2,200 mg L^{-1} of bentonite at 18^{o}C and 2 mg L^{-1} dissolved oxygen was 15 hours. No striped bass (*Morone saxatilis*) died when exposed to bentonite concentrations of up to 2,000 mg L^{-1} in 5 mg L^{-1} dissolved oxygen for 10 days; however, a LC_{20} of 2,000 mg L^{-1} of bentonite was recorded when the striped bass were exposed to 2 mg L^{-1} oxygen at the same temperature.

O'Connor *et al.* (1976) exposed estuarine fishes (white perch, spot, Atlantic silverside, mummichog, and striped killifish) to suspensions of fuller's earth (a commercial clay preparation) or sediment from the Patuxent River, Maryland. They found that the most sensitive adult estuarine fish (the Atlantic silverside *Menidia*

menidia) experienced 10% mortality after 24 hours exposure to 570 mg L^{-1} of fuller's earth. Fish were more resistant to the effects of natural sediments, with three times as much natural sediment often needed to produce the same lethal response as that caused by fuller's earth.

These studies show that the concentrations of suspended solids needed to cause mortality are at least an order of magnitude higher than the concentrations observed in the water column of the San Francisco Estuary during disposal events. Although lethal concentrations for the most sensitive species are similar to those measured adjacent to disposal barges and in the lower water column immediately following disposal (USCOE, 1976c), the experimental data showed that fish have to be exposed to such concentrations for several hours in order for death to occur (Peddicord *et al.*, 1975; O'Connor *et al.*, 1976). The plumes of high concentrations of suspended solids that occur during aquatic disposal of dredged material last only minutes. Furthermore, pelagic fishes may avoid regions of high concentrations of suspended sediments during disposal activities (Hirsch *et al.*, 1978). The need to avoid areas consistently could have an effect upon a population due to loss of suitable habitat and could also affect fishing success. The cumulative effect of several disposal events in sequence upon concentrations of suspended sediment in the water column has not been investigated. It is possible that fish could be exposed to higher concentrations of suspended sediments at such times.

Mortality in adults is not the only endpoint by which the effects of suspended sediments may be measured. The potential for sub-lethal impacts of suspended sediments upon fish, or for lethal effects upon sensitive life-stages, has not been investigated in San Francisco Bay, although such effects may occur at concentrations considerably lower than those resulting in mortality. O'Connor *et al.* (1976) demonstrate that juvenile fish were more sensitive to suspended sediments than adults. Young-of-the-year white perch suffered 100% mortality after exposure to 750 mg L^{-1} fuller's earth for 20 hr, while an LC_{10} value (10% mortality) for adults of this species was 7,910 mg L^{-1} after 20 hr.

O'Connor *et al.* (1977) measured sub-lethal responses in seven estuarine fish (striped bass and oyster toadfish, in addition to the five species listed above) exposed to natural and estuarine sediments and fuller's earth. The results showed that suspended sediment concentrations produced during dredging and disposal activities can produce physiological stress to estuarine fish. Examples of such stress included high rates of liver glycogen depletion and disruption of gill tissue. As part of the same study, Neumann *et al.* (1982) found that respiration by adult striped bass in the laboratory while swimming at 31.7 cm sec^{-1} was unaffected by exposure to 1,320 mg L^{-1} of Patuxent River sediment. At a higher swimming speed (49 cm sec^{-1}) respiration was depressed relative to control fish swimming in filtered water. At higher temperatures, significant depression in respiration was observed at the slower swimming speed. Decreased oxygen consumption will limit aerobic physiological processes, placing fish under stress.

Contaminated sediments may have additional impacts, or produce responses in organisms at lower concentrations than uncontaminated sediments. Further studies are required to examine physiological indicators of stress, particularly those connected

with reproduction. Egg or larval life-stages may also be expected to be more sensitive to suspended sediments than adult fish. It is also possible that transient increases in turbidity could influence the behavior of adult or juvenile fish, including forage species. Such changes in behavior could result in loss of habitat and reduce fishing success.

B. INVERTEBRATES

Peddicord *et al.* (1975) examined the lethal effects of suspended minerals on invertebrates in the laboratory. As with fish, significant variation in sensitivity occurred among species. Several invertebrate species from San Francisco Bay were relatively insensitive to the mineral suspensions employed. At kaolin concentrations of 100,000 mg L^{-1}, *Crangon fraciscorum* demonstrated 25% mortality after 5 days, *Mytilus edulis* (2.5 cm in shell length) 10% mortality after 5 days, *M. edulis* (10 cm in shell length) 10% mortality after 11 days, and two species of tunicates (*Molgula manhattensis* and *Styela montereyensis*) 10% mortality after 12 days. A few invertebrates were more sensitive to suspended kaolin, including the Dungeness crab (*Cancer magister*). The 200-hour LC_{10} for this species was calculated at 10,000 mg L^{-1}, and the LC_{50} at 32,000 mg L^{-1}. Mortality among invertebrates tested in the laboratory occurred at suspended sediment doses (concentration times length of exposure) well above those expected to occur due to dredging and disposal activities.

Peddicord *et al.* (1975) also showed that changes in dissolved oxygen and temperature could influence the sensitivity of organisms to suspended solids. The shrimp *Crangon nigricauda* (from Bodega Bay) was exposed at 10°C to bentonite at dissolved oxygen concentrations of 2 or 5 mg L^{-1}. At 5 mg L^{-1} dissolved oxygen, approximately 75% of the test organisms survived exposure for 240 hr to 9,000 mg L^{-1} of bentonite. At 2 mg L^{-1} dissolved oxygen, exposure to 7,000 mg L^{-1} bentonite caused mortality of all individuals after about 185 hr. While these data suggest an interaction between suspended sediment exposure and dissolved oxygen when exposures last for a long time (185 to 240 min), depressions of dissolved oxygen that occur during dredging and disposal operations generally persist for only a few minutes.

Although mortality of the invertebrates studied occurred only at very high doses of suspended solids, other life stages may be more sensitive, particularly if endpoints other than mortality were studied. Abnormal egg development in oysters and clams has been demonstrated after exposure to high concentrations of silt for 7 to 14 days. Larvae of the American oyster (*Crassostrea virginica*) were affected by exposure to 750 mg L^{-1} of silt (Sullivan and Hancock, 1977). In addition, suspended sediments may accumulate to higher concentrations during frequent use of a disposal site, causing adverse sub-lethal responses.

C. PLANKTON

Because plankton are a primary source of food (either directly or indirectly) for organisms in the Estuary, the impact of increased concentrations of suspended solids upon these organisms is potentially very important. This is particularly the case for phytoplankton, as their lack of mobility could increase their exposure to suspended sediment plumes from dredged material disposal. The attenuation of light due to increased concentrations of suspended solids in receiving waters could also reduce

net phytoplankton productivity, thereby reducing the availability of food for higher trophic levels.

The correlation between the light extinction coefficient and suspended particulate matter in San Francisco Bay implies that the availability of light for photosynthesis in estuarine waters is predominantly a function of suspended solid concentrations. The photic depth (the maximum depth at which photosynthesis is possible) varies from about 5 m in the Central Bay to less than 1 m in the shallows of Suisun Bay, reflecting the concentration of suspended solids in the Estuary (Cloern, 1987).

For dredging and dredged material disposal to affect phytoplankton productivity in the Estuary, concentrations of suspended solids in the photic zone would have to be increased significantly for extended periods of time. Experiments conducted to date, however, suggest that the increased concentrations of suspended solids from dredging and disposal operations are only short-lived phenomena, although sediment concentrations in the water column might increase in response to frequent disposal events. Temporary depressions of primary production on a local scale are possible and have been documented in other systems (e.g., see Sullivan and Hancock, 1977; Hirsch *et al.*, 1978). Studies of turbidity increases caused by dredging and disposal activities also indicate that any major increases in suspended sediment concentrations occur in the lower water column, below the level of the photic zone.

7. Physical Effects of Sediment Disposal on Benthic Communities

Besides the potential for dredging and the aquatic disposal of contaminated sediments to exert toxic effects to the benthos (see Section V.D.2), there will be unavoidable physical impacts upon benthic communities at all dredging sites. These impacts are the physical removal of species at the dredge site, possible smothering of organisms adjacent to the dredging site (Sherk, 1971), possible alterations in the physical characteristics (e.g., grain size) of the remaining substrate at the site (Boesch, 1982), and potential changes in the nature of recolonization of the site. Most of these impacts also occur at disposal sites and are considered below. The loss of benthic species by physical removal or perhaps by smothering or burial in areas adjacent to dredging has not been studied in the San Francisco Estuary. Some of the areas dredged are highly contaminated and exhibit unusual benthic faunal assemblages (e.g., Islais Creek, dominated in its inner reaches by pollution-tolerant polychaete species) compared to other sites in the Bay. By contrast, many of the sites receiving frequent dredging are likely (by virtue of their degree of siltation) to exhibit the usual benthic communities, dominated by short-lived, opportunistic species (Hirsch *et al.*, 1978; Nichols and Pamatmat, 1988).

An obvious impact of the aquatic disposal of dredged material is the burial of benthic organisms, especially sessile species. Many infaunal organisms possess the ability to burrow through sediments until they reach the sediment/water interface, but buried epifaunal organisms normally perish (Hirsch *et al.*, 1978). Work in Monterey Bay (see Hirsch *et al.* [1978]) showed that burrowing species migrate through dredged material tens of centimeters deep, but only under circumstances where the grain size of the newly deposited sediment is similar to that of the species' normal habitat.

The frequency of use of a disposal site also affects the nature of the benthic community at that site. The frequent use of the Alcatraz disposal site has resulted in the selection of a very opportunistic community, as the changing substrate allows little time for organisms to establish themselves (SAIC, 1987a). Liu *et al.* (1975) found that there were few organisms at the Alcatraz site at certain times, but those present were characterized by an opportunistic lifestyle. Research in Monterey Bay also documented this characteristic at dredging and disposal sites (Hirsch *et al.*, 1978).

Benthic communities may be severely affected by the disposal of slurried dredge spoils, which often contribute to the formation of fluid mud, or "fluff," a dense, near-bottom suspension overlying more consolidated sediments. There is no exact definition of fluid mud, and different authors have adopted different thresholds of concentration to differentiate such material from sediments. Fluid mud exists due to the phenomenon of "hindered settling," in which forces act to prevent the deposition of individual particles. The resulting mass moves as a fluid, finally settling in depressions where slow consolidation occurs (Barnard, 1978). These muds can exhibit low concentrations of dissolved oxygen and do not generally provide the physical support to allow for the upward migration of burrowing species (Hirsch *et al.*, 1978).

It has been amply demonstrated that the local benthic communities are heavily influenced by the grain size of sediments (Nichols, 1979; Nichols and Thompson, 1985a, 1985b). Clearly, alterations to sediment grain sizes at disposal sites may exert marked effects on benthic communities. In order to overcome such effects, the "like-on-like" principle is often used, wherein material disposed at a site is restricted to sediments with a grain-size distribution that is similar to that at the disposal site. Thus, sandy material dredged from the bar outside the Golden Gate is deposited at the Bar site, but material of smaller grain size, from within the Estuary, is not deposited at that location. However, the disposal sites within the Estuary are dispersive in nature, and the subsequent transport of disposed sediments may have an impact upon other areas of the Bay. Fishing interests in the community state that rocky and sandy areas of Central Bay have been covered by silt and clay due to the disposal of dredged material, and that subsequent changes in sediment grain size have resulted in the destruction of valuable habitats for rockfish and other commercial species (BCDC, 1988a).

Few data exist with which to evaluate this claim (BCDC, 1988a). Sandy substrates are only found in regions with higher current velocities such as in the deeper channels of the Estuary (Nichols and Pamatmat, 1988). It is unlikely that easily suspended silt and clay particles would be deposited in such areas. SAIC (1987a) sampled 14 stations in the Central Bay using REMOTS® camera technology, and found evidence of sediment deposition only in relatively sheltered, nearshore areas. Although more data are needed to make definitive conclusions, these data suggest that extensive deposition of fine particles is not occurring in the high-energy areas of Central Bay. Temporary deposition of fine particles in high-energy environments undoubtedly occurs, especially during slack water, and such deposition might be more frequent during heavy use of a disposal site. Whether these deposits accumulate and consolidate to the point of resisting erosion is unknown.

The recolonization of dredged areas and disposal sites will vary depending upon the local environment. In general, dredged regions and disposal sites are recolonized rapidly, with complete recovery often occurring within one year (Hirsch *et al.*, 1978; Nichols and Pamatmat, 1988). In those localities where sediments are normally disturbed by wind and tide, recovery is usually faster, as a pool of organisms exist which are well-adapted to the conditions. Studies in Monterey Bay do not show a particular sequence for recolonization, but the particle size of newly deposited material appears to exert a great influence upon the nature of the developing community (Hirsch *et al.*, 1978; Wright, 1978). Of course, complete recolonization of a dredging or disposal site will only occur after these activities have ceased. As long as disposal sites are used continuously (such as Alcatraz), only the most opportunistic organisms will be able to successfully exploit these environments.

Nichols and Pamatmat (1988) point out that San Francisco Bay benthos are reproductively active for a large portion of the year and can quickly colonize disturbed areas. This fact, combined with the highly dynamic benthic environment that characterizes much of the Estuary, indicates that benthic communities in the Estuary are resilient to the physical impacts of dredging and disposal activities, just as they are adapted to the natural environment that exhibits both high turbidity and exceptional sediment mobility. This also suggests that if disposal were to cease at any of the three aquatic sites in the Estuary, the benthic community would be reestablished quickly at these locations.

E. PRESENT TESTING REQUIREMENTS

This section outlines the chemical and biological testing that is performed to assess the potential impacts of dredging and disposal of dredged material in inland waters, in the ocean, and on land.

1. Inland Waters

A. NATIONAL POLICIES

As previously described, the USCOE issues permits for the disposal of dredged material into inland waters. The legal authority to issue these permits is granted to the USCOE by Section 404 of the *Clean Water Act*. Section 404 also contains general guidelines intended to prevent unacceptable adverse effects due to dredged material disposal in the aquatic environment. These guidelines include provisions that the disposal will not result in violations of applicable water quality standards (after consideration of dispersion and dilution), or contribute to significant degradation of the waters of the United States. Demonstration of compliance with the two provisions often requires that chemical and biological testing of dredged sediment be performed. Findings of compliance with water quality objectives are based largely on Section 401 of the *Clean Water Act*, which gives individual States the authority to develop water quality objectives. States review dredging permit applications to ensure that they comply with these objectives, through a process known as "water quality certification". For the San Francisco Bay and Delta, this review is the responsibility of the San Francisco Bay and Central Valley Regional Water Quality Control Boards (see Section III). State water quality agencies, such as the Regional Boards, have the independent

authority to require specific testing procedures that assess attainment of water quality objectives. Dredging permit applications are also subject to review by USEPA under Section 404 of the *Clean Water Act*.

Section 404 of the *Clean Water Act* also provides that technical guidelines and criteria for disposal be developed by the USEPA in conjunction with the USCOE, and that these be applied by the USCOE in selecting disposal sites and reviewing permit applications. These technical guidelines for disposal in inland waters appear in the *Federal Register* (USEPA, 1980) and in an interim guidance manual published by the Waterways Experiment Station of the USCOE (USCOE, 1976e). Elements of a detailed manual published jointly by the USEPA and the USCOE to provide guidance for the evaluation of discharges of dredged material into ocean waters (USEPA/USCOE, 1977) have also been employed in evaluating the disposal of dredged material in inland waters.

Dredged material from different locations is extremely variable in physical and chemical characteristics; the disposal of some materials may cause adverse environmental effects. The Waterways Experiment Station of the USCOE has therefore developed a method for evaluating the potential for adverse effects of sediments of varying quality, intended to allow for cost-effective testing while ensuring that the requirements set forth in the *Clean Water Act* and USEPA (1980) are met. Engler *et al.* (1988a) provide a detailed description of this approach, known as the "Federal Standard." The Federal Standard provides a consistent framework used by field offices of the USCOE in the implementation of the procedures specified by USEPA (1980) for the evaluation of proposals for dredged material disposal. The Federal Standard is one facet of a broader decision-making framework recently developed by the USCOE for the management of dredged material (Francingues *et al.*, 1985; Lee and Peddicord, 1988). This decision-making framework integrates appraisal of all alternatives for dredged material disposal (including inland aquatic disposal, ocean disposal, and upland disposal). Guidelines established by the USCOE are based both on operating experience and results from extensive research programs, including the Dredged Material Research Program (Saucier *et al.*,1978) and the ongoing Environmental Effects of Dredging Program (Engler *et al.*, 1988b).

The following discussion describes the Federal Standard as an introduction to the national policies of the USCOE and USEPA regarding the types of tests performed in evaluation of the potential environmental impacts of dredging and disposal of dredged material. Controversial aspects of these procedures are noted below.

The Federal Standard outlines a tiered approach (Table 19) for the testing of dredged material. Each tier is optional and may be waived if information is available to provide an adequate assessment of that tier, or if there is no reason to believe that unacceptable adverse effects (which are assessed on that tier) will occur.

The first tier consists of an evaluation of existing information, to determine whether there is evidence that contaminants are present at the dredging site in concentrations above background. This tier is known as the "exclusion clause." Information relating to previous tests of sediments at or near the dredging site, nearby point and non-point sources of contamination, and nearby natural mineral deposits are

Table 19. The 'Federal Standard' approach for the evaluation of proposals to dispose of dredged material in inland waters. After Engler *et al.* (1988a).

Tier I	**Initial evaluation**
	Evaluation of existing information and "reason to believe there is contamination."

Tier II	**Chemical testing**
Tier IIA	*Bulk sediment inventory*. Reason to believe dredged material is more contaminated than disposal site sediment and potential unacceptable adverse effects may occur.
Tier IIB	*Elutriate analysis*. Chemical analysis for contaminants of concern, contrast to appropriate water quality criteria and/or standards with consideration of mixing. Comparison to receiving water quality and/or bioassay when no standards exist.

Tier III	**Biological testing**
Tier IIIA	*Acute toxicity tests* (as appropriate) Water column (elutriate). Tests using dissolved and/or suspended phase. Use of the following organisms is suggested: mysid or grass shrimp, bivalve, larval bivalve, fish, or others. Benthic. Test uses solid phase. Use of a filter-feeder, a deposit-feeder, and a burrowing species from the following list is suggested: mysid shrimp, grass shrimp, amphipod, clam, polychaete, or other.
Tier IIIB	*Bioaccumulation* Water column. Test uses suspended solids phase and one of the following organisms: grass shrimp, clam, polychaete, or other. Benthic. Test uses the solid phase and one of the following organisms: clam, polychaete, or other.

reviewed. If there is no reason to believe that the material is contaminated, and if the dredged material is physically (grain size) and chemically similar to sediments at the disposal site, the sediment is excluded from further testing. For example, dredged material composed of sand or gravel may be excluded from testing because it is not likely to be significantly contaminated. However, in cases where contaminants are thought to be present above background, or if insufficient information is available, testing on the second tier may be conducted.

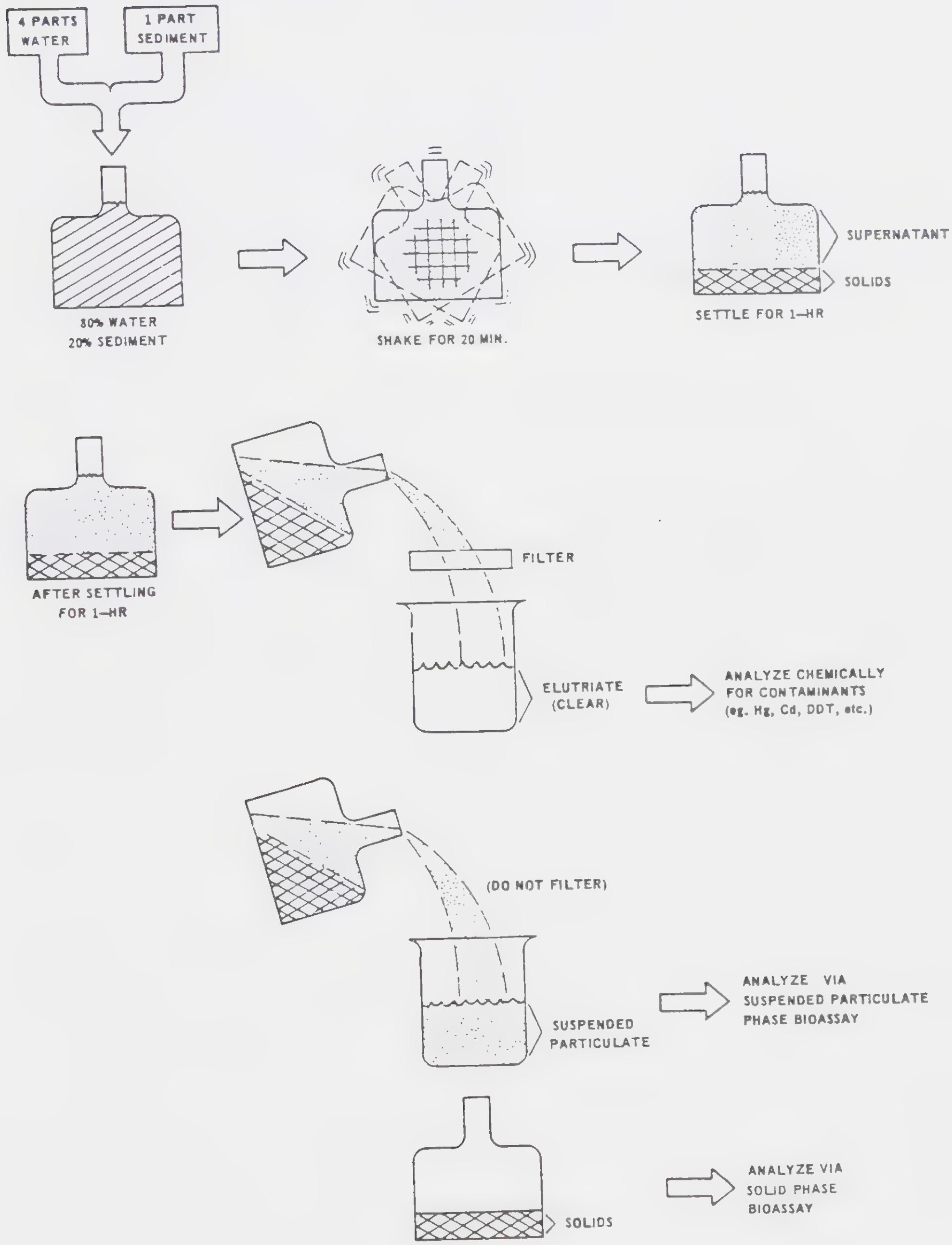
Chemical characterization of the dredged material takes place on the second tier (Table 19). Options for analysis on this tier include bulk chemical analysis and elutriate testing. Bulk chemical analysis of sediment is a procedure that uses a strong extractant to release all the contaminants present in the sediment tested, including those in the crystalline matrix (Section V.D.1.). Concentrations of contaminants in sediments to be dredged are compared to concentrations in sediment at the disposal site (USEPA, 1980). Testing on the third tier may be required if dredging site sediment is substantially more contaminated than disposal site sediment. Use of the disposal site as a reference area, rather than an uncontaminated site, is one controversial aspect of the testing procedures. This approach could allow the continued disposal of contaminated dredged material at sites, such as Alcatraz, that are already contaminated (C. Krueger, USEPA, personal communication). Testing on the third tier may also be required if there is thought to be a potential for unacceptable adverse effects due to the presence of contaminants.

Elutriate testing (USEPA/USCOE, 1977) is performed to evaluate release to the water column of contaminants in interstitial water or loosely bound to sediment particles. An elutriate from a sediment sample is obtained by mixing sediment from the dredging site with water from the disposal site for 30 minutes, followed by 1 hr of settling. The supernatant is then filtered to remove suspended particles prior to chemical analysis. Figure 35 illustrates these procedures. The results of the elutriate test are compared to water quality objectives. If these results suggest that a potential for adverse effects exists after aquatic disposal, further testing on the third tier may be required. Further testing may also be required if there are no relevant water quality standards or if available standards are thought to be inappropriate or inadequate.

On the third tier, bioassays are used to evaluate toxicity and bioaccumulation of contaminants present in the sediment to be dredged. The potential for adverse impacts in the water column may be assessed using either liquid or suspended particulate phase bioassays (Fig. 35). Potential impacts to benthic organisms may be assessed using bioassays of the solid phase (Fig. 35). In benthic bioassays, three species occupying different ecological niches at the disposal site are generally used: a filter-feeder, a deposit-feeder, and a burrowing species. If bioaccumulation of contaminants at the dredging or disposal site is of concern, contaminant uptake may be measured. In the laboratory this is done using survivors of the toxicity bioassays, if enough organisms survive the test. Bioaccumulation may also be evaluated in the field.

Data from tiers 2 and 3, which assess the impact of contaminants in the water column (i.e., elutriate tests and bioassays using dissolved or suspended particulate phases), are interpreted with consideration of mixing (USEPA, 1980). Impacts on biota at the disposal site will be a function of both contaminant concentration and the

<u>Fig. 35</u>. Derivation of the dissolved, suspended particulate, and solid phases for use in chemical and biological testing of sediment samples. After Fong *et al.* (1982).



duration of exposure. However, the prediction of spatial patterns in these two factors in the field is a complex task. A simplified approach for calculating the projected surface area of the mixing zone (USCOE, 1976e) is the method commonly used. Because of the undeveloped state of technical guidance on this topic, application of the mixing zone concept is left largely to the subjective interpretation of the district office (Lee and Peddicord, 1988). The Waterways Experiment Station is currently developing numerical models of mixing for use on microcomputers; these will be available in late 1989 (R. Engler, USCOE, personal communication).

The degree of mixing allowed in assessment of water column impacts of dredged material disposal is a controversial topic. Some consider the mixing zones allowed by the USCOE to be excessively permissive (Brian Melzian, USEPA, personal communication). Particularly contentious are cases such as the proposed Oakland Harbor deepening (USCOE, 1988a) and U.S.S. Missouri Homeporting([U.S. Navy, 1987) where significant mortality is observed in bioassays but the USCOE still concludes that water quality impacts are not likely. USCOE application of the mixing zone concept may not adequately account for potential cumulative effects due to repeated disposal events over short periods of time (Segar, 1988; Brian Melzian, USEPA, personal communication). The potential for such cumulative effects is discussed in Section V.D. Segar (1987) has also criticized USCOE calculations of dilution in the mixing zone.

Assessments of the impacts of aquatic disposal focus on the solid phase. Engler *et al.* (1988a) state that "an overwhelming preponderance of evidence" from years of study indicates that, in general, the potential for water column impacts due to contaminants released from dredged material is negligible. Such impacts are considered to be sufficiently unlikely to occur that evaluations should focus on the material that is deposited on the bottom, rather than on material in the water column, which is subject to rapid dispersion and dilution in most cases. The USCOE does recognize, however, that there are conditions (such as poor mixing, already degraded conditions, or shallow water) that may require water column testing.

The testing guidelines require the use of mortality as an end-point in toxicity bioassays because its ecological consequences are considered more easily interpretable than those of sublethal responses (USEPA, 1980; Lee and Peddicord, 1988). However, the adequacy of using mortality of individuals to assess ecosystem impacts can be questioned. Recently investigators have begun to identify sublethal responses that may be used to predict potential population and ecosystem impacts associated with dredged material disposal. In 1982 the USCOE and the USEPA initiated a 6-yr, $7.2 million study (the "Field Verification Program") of the effects of dredged material disposal in aquatic, wetland, and upland environments (Gentile *et al.*, 1988; Peddicord, 1988). This included a major effort to verify the predictive accuracy of various sublethal measures of the effects of aquatic disposal. Several of the measures exhibited a clear, reproducible relationship with exposure to sediment in the laboratory and corresponding sensitivity in the field; these included scope for growth, reproduction, and bioaccumulation. Other sublethal response endpoints could not be fully field-verified (bioenergetic measurements and intrinsic rate of population growth) or were inconsistently related to exposure to dredged material (adenylate energy charge, sister chromatid exchange, and histopathology) (Peddicord, 1988).

The regulations for inland aquatic disposal of dredged material do not offer firm guidance on the difficult problem of aquatic bioassay interpretation. Consequently, interpretation of the potential for adverse effects due to proposed projects in the field is largely subjective.

The Federal Standard represents a useful scheme for implementing the testing procedures prescribed by USEPA (1980) for disposal of dredged material into inland waters. However, application of these procedures, particularly the interpretation of test results, relies heavily on subjective judgement. Critics of the testing scheme argue that an over-reliance on professional judgement may result in lenient regulation of contaminated material (B. Melzian, USEPA, personal communication; C. Krueger, USEPA, personal communication). The development of objective criteria to be used in determining the need for further testing and the ecological significance of test results would improve this scheme. Other controversial aspects of the procedures include the use of the disposal site as a reference site, the use of test organisms that may be relatively insensitive, the lack of sublethal testing, and the application of the mixing zone concept.

Although no numeric sediment quality criteria for contaminants exist at present, the establishment of such criteria is receiving considerable attention at the national and regional levels (Shea, 1988; Chapman, 1989). Interim sediment quality criteria have been proposed for Puget Sound by the State of Washington, Department of Ecology. Sediment quality criteria could improve the objectivity of assessments of the potential for toxic effects due to dredging and disposal of dredged material. There are two principal approaches to development of national sediment quality criteria. These are based on 1) modeling of equilibrium partitioning of contaminants between sediment, water, and biota; and 2) synoptic approaches (e.g., "apparent effects thresholds") relating contaminant concentrations in sediment to biological effects measured using bioassays or benthic population studies. Unfortunately, variation in sediment characteristics and the complexity of contaminant behavior in sediment have led to a spirited debate regarding the satisfactory application of either of these approaches (for a full discussion of equilibrium partitioning and apparent effects thresholds see Davis *et al.*, 1989).

B. LOCAL IMPLEMENTATION OF NATIONAL POLICIES

The policies and philosophies of the USCOE San Francisco District parallel those of the Waterways Experiment Station. In 1987 the San Francisco District issued a draft Public Notice (PN 87-1; USCOE, 1987b), which incorporated several of the concepts included in the Federal Standard. The draft Notice outlined a tiered approach to testing and focused attention on the solid phase as having the greatest potential for adverse impacts in the environment of the disposal site. This represented a significant departure from prior requirements specified by Public Notice 78-1 (USCOE, 1978), which had established a testing program that required assessment of water column impacts using only the elutriate test. Draft PN 87-1, however, was never officially adopted by the San Francisco District.

At present, requirements for the testing of sediments proposed for dredging are not formalized in a Public Notice. However, elements of the scheme presented in draft PN 87-1 are used in the evaluation of permit applications (Fig. 36; P. Cotter, USEPA, personal communication; USCOE, 1988d). Dredged material may be excluded from chemical or biological testing if it meets specific criteria, as described for Tier 1 of the Federal Standard. If the material does not meet the exclusion criteria, chemical analyses are conducted, as in Tier 2 of the Federal Standard. Chemical analyses of bulk sediment are performed, comparing results from the material proposed for dredging with data from sediments at the disposal site. Table 20 lists the physical and chemical parameters measured in bulk sediment testing. If results from the dredging site indicate "substantially greater" contamination than at the disposal site, additional testing is required. Options for additional testing are those described under Tier 3 of the Federal Standard.

As mentioned above, the Regional Boards have the independent authority to require specific testing procedures that assess attainment of water quality objectives. The SFBRWQCB requires that any dredged material that is tested by the chemical and biological methods discussed in the preceding paragraph must also be subjected to a bioassay using the larval stage of a bivalve and the suspended particulate phase. The results from this assay are used by the SFBRWQCB in its decision to grant or withhold water quality certification.

As described in Section IV. above, the Sacramento District has not issued any major permits for open water disposal of dredged material in recent years. Dredged material from large projects in the area under the jurisdiction of the Sacramento District is typically disposed of to upland sites, or used for habitat enhancement. Testing requirements for upland disposal are discussed below.

2. Ocean Waters

A. NATIONAL POLICIES

Historically, most sediment dredged from San Francisco Bay has been disposed in the Bay. Recently, however, the option of ocean disposal of sediment dredged from San Francisco Bay has received considerable attention (USCOE, 1988b). The appropriateness of continued in-Bay disposal has been questioned (e.g., Segar, 1988) because the Alcatraz disposal site may have a limited capacity to accept dredged material at the rate it is currently disposed, and the chemical impact of disposal at Alcatraz may have been underestimated (see Section V.D. of this report). Section 103 of the *Marine Protection, Research and Sanctuaries Act* (PL 92-532, as amended) requires the USCOE to regulate the transport of dredged material for dumping into ocean waters through a permit system. The USEPA and the USCOE are required to conduct cooperative reviews of the potential environmental impacts of all ocean dumping proposals. The primary intent of Section 103 of the *Marine Protection, Research and Sanctuaries Act* is to regulate strictly any adverse ecological effects of ocean dumping.

Permit reviews are performed in accordance with guidelines published in the *Federal Register* by the USEPA (1977). The guidelines require the use of toxicity and bioaccumulation assays to assess the possible adverse effects of ocean disposal,

Fig. 36. Testing scheme presently used to evaluate the potential environmental effects of dredged material disposed into the Bay (P. Cotter, USEPA, personal communication; USCOE, 1988d)

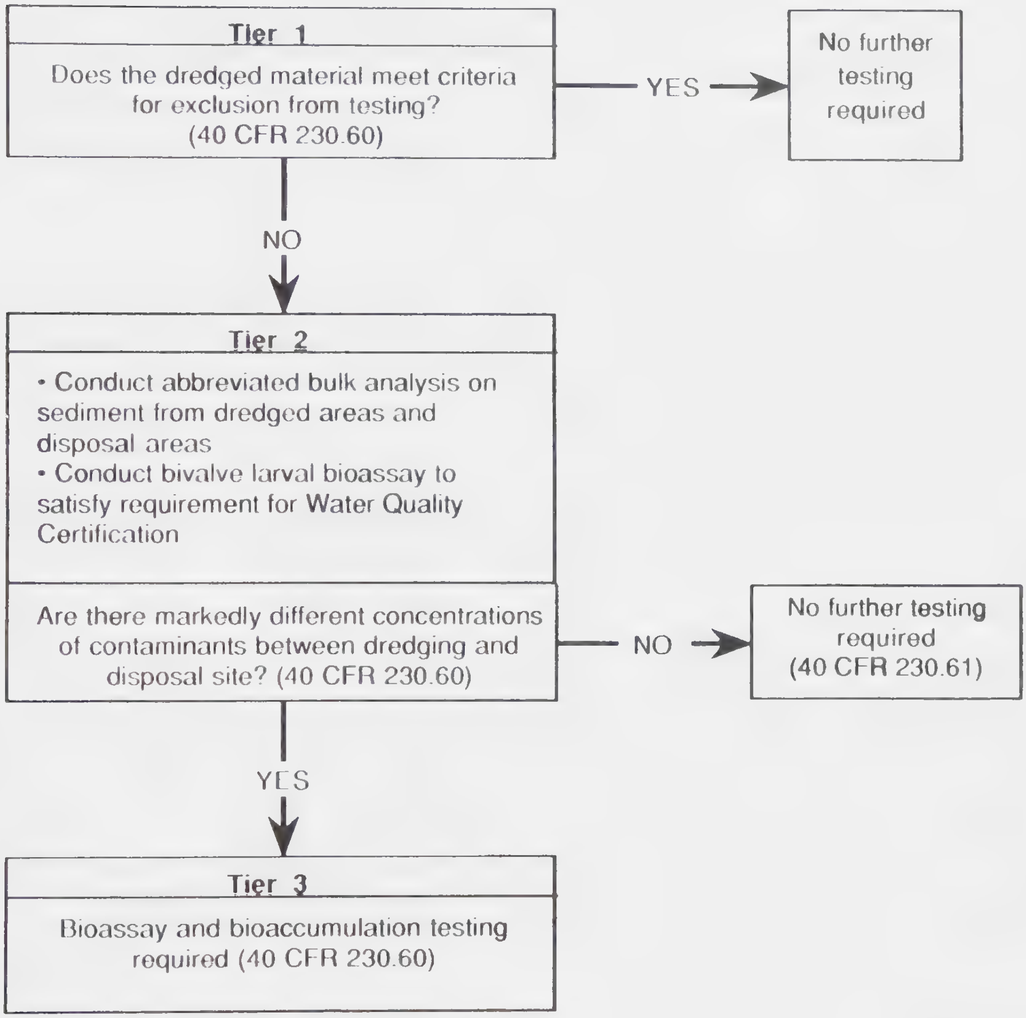


Table 20. Physical and chemical parameters measured in bulk sediment testing (D. Smith, USCOE, personal communication).

PHYSICAL CHARACTERIZATION

1. Grain size analysis
2. Total solids/water content (% solids)

CHEMICAL CHARACTERIZATION (all values reported on both dry and wet weight bases, detection limits in parentheses)

1. **Metals** (detection limits in mg/kg)

Antimony	(1.0)
Cadmium	(0.1)
Chromium	(0.1)
Copper	(0.1)
Lead	(0.1)
Mercury	(0.02)
Nickel	(0.1)
Silver	(0.1)
Selenium	(0.1)
Thallium	(1.0)
Zinc	(2.0)

2. **Nonmetals** (detection limits in mg/kg)

Arsenic	(0.1)
Cyanide	(0.02)
Total and water soluble sulfides	(0.1)

3. **Pesticides** (detection limits in ug/kg)

Aldrin	(0.5)
Chlordane and related compounds	(5.0)
Dieldrin	(0.5)
DDT and derivatives	(1.0)
4,4'-DDE	(0.5)
Endrin	(0.5)
Endosulfan I	(2.0)
Endosulfan II	(0.5)
Endosulfan sulfate	(10.0)
Hexachlorocyclohexane isomers	(0.5-1.0)
Toxaphene	(30.0)

4. **Organics** (detection limits in ug/kg, except for TOC)

Oil and grease	(20.0[a])
Organotins (mono, di, and tributyltin)	(1.0)
Phenols:	
Total	(20.0-100.0)
Total chlorinated	(20.0-100.0)
Pentachlorophenol	(100.0)
Phenol	(20.0)
2,4-Dichlorophenol	(20.0)
2,4-Dimethylphenol	(100.0)
Polychlorinated biphenyls:	
Total	(20.0)
Aroclor 1242	(20.0)
Aroclor 1254	(20.0)
Aroclor 1260	(20.0)
Phthalates, total	(10.0)
Total organic carbon	(0.1%)

Polynuclear aromatic hydrocarbons:	
Total	(20)
Acenaphthene	(20)
Acenaphthylene	(20)
Anthracene	(20)
Benzo(a)anthracene	(20)
Benzo(a)pyrene	(20)
Benzo(g,h,i)perylene	(20)
Benzo(b)fluoranthene	(20)
Benzo(k)fluoranthene	(20)
Chrysene	(20)
Dibenzo(a,h)anthracene	(20)
Fluoranthene	(20)
Fluorene	(20)
Indeno(1,2,3-cd)pyrene	(20)
Naphthalene	(20)
Phenanthrene	(20)
Pyrene	(20)

[a]Wet weight

except for cases where the dredged material meets certain criteria for exclusion from testing. Liquid, suspended particulate, and solid phases of the material must be evaluated for every proposed discharge. A joint USEPA/USCOE *Technical Committee on Criteria for Dredged and Fill Material* published a manual recommending testing procedures for implementation of the regulatory program (USEPA/USCOE, 1977). This "Implementation Manual" was mentioned in the previous Section, as it contains detailed guidance on testing procedures, elements of which have been adopted informally for use under Section 404 of the *Clean Water Act.* The Implementation Manual is currently being revised by the USEPA and the USCOE. A revised Draft Implementation Manual has been prepared (August 1989) and is under review.

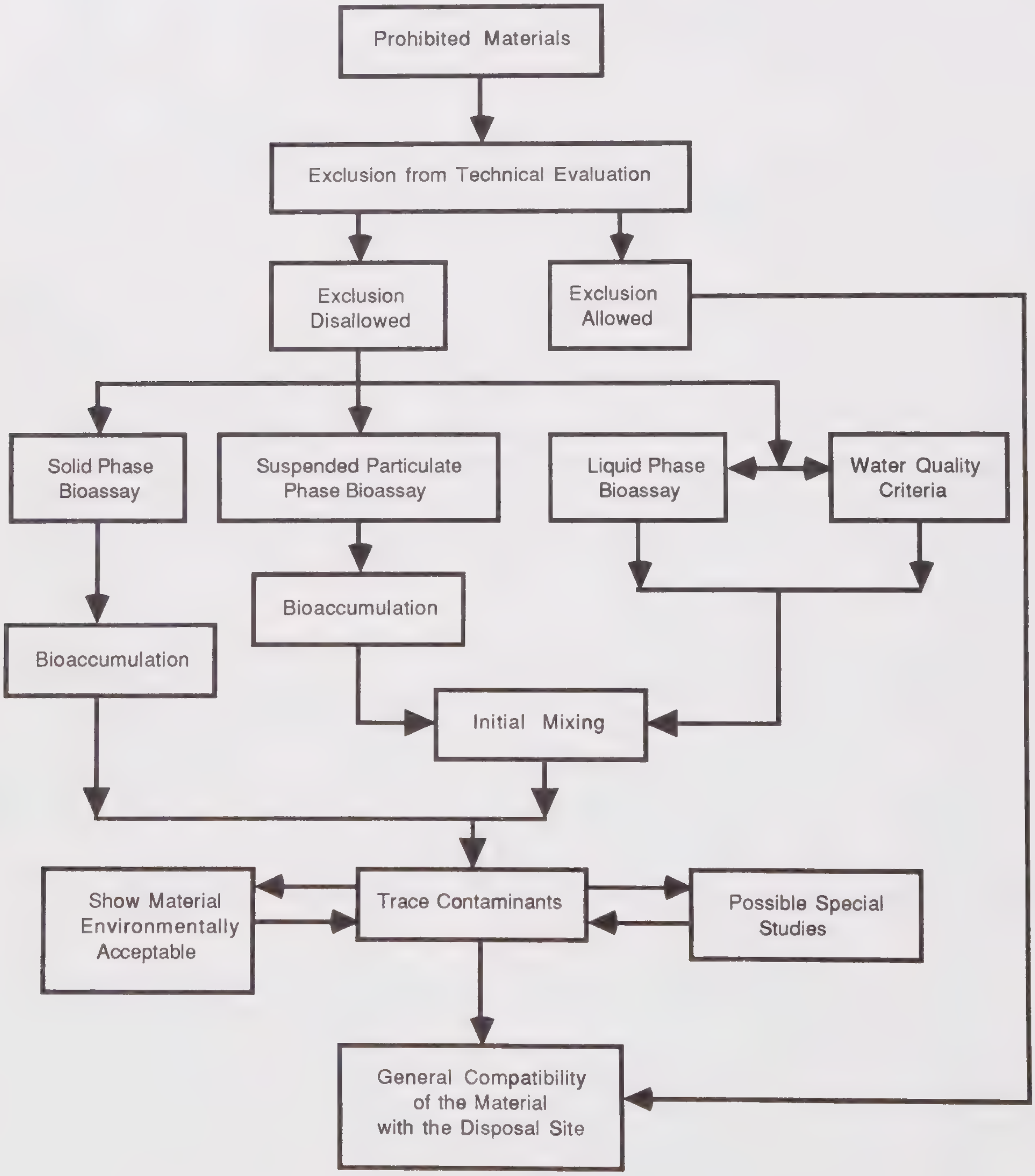
In general, the components of the testing scheme for ocean disposal are similar to those of the Federal Standard. The principal differences are that toxicity and bioaccumulation assays are mandatory, and that guidance on the interpretation of test results is included explicitly in Section 103 of the *Marine Protection, Research and Sanctuaries Act.* These differences are highlighted in the following discussion.

Figure 37 outlines the testing requirements for the ocean disposal of dredged material. Dredged material that does not satisfy exclusion criteria must be tested in the liquid, suspended particulate, and solid phases (in the Federal Standard the sequence and selection of these tests are options, not requirements). The liquid phase (elutriate, obtained as described in the preceding Section) may be analyzed chemically and the results compared to established water quality objectives. Liquid phase bioassays are required if the water quality objective approach is not taken or when there is concern about the possible synergistic effects of certain contaminants. These bioassays are conducted with one plankton species (preferably a zooplankter), a crustacean or mollusc, and one fish species.

Biological tests are the sole means used to evaluate the suspended particulate phase. Biological tests are conducted with species from the same groups tested in the liquid phase bioassays. As in the Federal Standard, emphasis is placed on the evaluation of the solid phase, which is considered to have the greatest potential for detrimental environmental impacts. Organisms subjected to bioassays should include a crustacean, an infaunal bivalve, and an infaunal polychaete. All evaluations are also required to estimate the potential for bioaccumulation of contaminants from the suspended particulate and solid phases. When a historical precedent exists for a proposed operation, bioaccumulation from the solid phase is best evaluated in the field.

Section 103 of the *Marine Protection, Research and Sanctuaries Act* requires two additional evaluations that are not prescribed by Section 404 of the *Clean Water Act*. The presence of specific contaminants (organohalogens; mercury; cadmium; oils; and carcinogens, mutagens, or teratogens) in excess of trace amounts must be determined for all three phases of the dredged material. This evaluation also ensures compliance with provisions of an international agreement, the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter (the "London Dumping Convention" [Edgar and Engler, 1984]). The term "trace," as used in Section 103, however, does not have its usual analytical meaning. As defined in the *Federal Register*, trace concentrations are those which are too low to cause environmental effects and are evaluated in terms of persistence, toxicity, and bioavailability. Trace

Fig. 37. Sequence of procedures for the technical evaluation of dredged material prior to ocean disposal. Adapted from USEPA/USCOE (1977).



contaminants are evaluated through the use of water column and benthic acute toxicity and bioaccumulation tests. The final step in technical evaluation of dredged material prior to ocean disposal is an assessment of the general compatibility of the material with the existing sediments at the disposal site.

All interpretations of data from chemical analysis of the liquid phase and biological testing must take initial mixing into account. The regulations define initial mixing as the dispersion and diffusion of the discharged material that occurs within 4 hr after dumping. Concentrations of contaminants cannot exceed standards beyond the boundaries of a disposal site during the 4-hr mixing period, and cannot exceed them at any location after the 4-hr mixing period. USEPA/USCOE (1977) offers guidance on estimation of maximum concentrations of the liquid and suspended particulate phases found at the disposal site. The mixing concept is also incorporated into the experimental design of solid phase bioassays. These tests evaluate the effects of chemicals associated with layers of sediment near the disposal site boundary. The interpretation of results from laboratory bioaccumulation assays is also required to include assessment of the effects of mixing; this assessment is subjective because no objective or quantitative method has yet been developed.

The Implementation Manual emphasizes that each aquatic bioassay prescribed is an imprecise predictor of effects in the aquatic environment. Section 103 of the *Marine Protection, Research and Sanctuaries Act* offers guidance for the interpretation of toxicity test results that is firmer than that offered by the USCOE for the disposal of dredged material to inland waters under Section 404 of the *Clean Water Act*, based on statistically significant responses in tests of sediment to be disposed relative to controls.

B. LOCAL IMPLEMENTATION OF NATIONAL POLICIES

Consideration of ocean disposal for sediment dredged from Oakland Harbor and the Alcatraz disposal site (USCOE, 1988a) gave rise to the only significant local application in recent years of the Implementation Manual procedures for the evaluation of potential adverse effects of dredged material disposal in the marine environment. For the most part, this evaluation followed the Implementation Manual protocol. An exception to this general rule was the substitution of bulk sediment testing for elutriate testing (USCOE, 1988a; Word *et al.*, 1988). This substitution was made because contaminants were not detected in early rounds of elutriate analyses, yet concern remained over the potential remobilization of contaminants associated with the material to be dredged. Table 21, which lists the contaminants analyzed in bulk sediment samples and bioaccumulation assays of sediments from the Alcatraz disposal site, provides an example of the types of contaminants measured in these evaluations. As specified by the Implementation Manual, biological tests of the suspended particulate and solid phases used several species that occupy different environmental niches.

Table 21. Parameters analyzed in the evaluation of potential impacts of ocean disposal of material dredged from the Alcatraz disposal site. After USCOE (1988b).

Parameter	Sediment	Clam Tissue	Worm Tissue
Antimony	X	X	X
Cadmium	X	X	X
Copper	X	X	X
Lead	X	X	X
Mercury	X	X	X
Nickel	X	X	X
Organochlorines (EPA Method 608)	X	X	X
Polynuclear Aromatics (EPA Method 610)	X	X	
Total Organic Carbon	X		
Grain Size	X		

3. Upland Disposal

A. NATIONAL GUIDANCE

In contrast to the situation for aquatic disposal options, the USCOE has no explicit legal authority to establish guidelines for the evaluation of potential adverse environmental effects of upland disposal, except where drainage from such sites flows into waters of the United States. The upland disposal option is included in the framework developed by the USCOE for the management of dredged material, and the Waterways Experiment Station has conducted extensive research to refine this method of disposal (Francingues *et al.*, 1985; Lee and Peddicord, 1988). In cases where dredged sediments are highly contaminated, the USCOE considers that confined upland disposal is often the only viable disposal alternative.

In spite of the lack of an explicit requirement to establish testing guidelines for upland disposal, the Waterways Experiment Station of the USCOE has developed an array of procedures to predict the environmental effects of this alternative (Saucier *et al.*, 1978; Francingues *et al.*, 1985; Lee and Peddicord, 1988). This research began with the Dredged Material Research Program in the 1970s (described previously in Section IV.B.). More recent research was conducted under the Long-Term Effects of Dredging Operations (LEDO) Research Program and the Field Verification Program (FVP) (Engler *et al.*, 1988b). Research on the effects of upland disposal has focused on the assessment of contaminant movement from upland sites through several pathways.

Sedimentation of dredged material placed in an upland site produces a clarified supernatant that is released from the site as an effluent. Under the LEDO Program, the Waterways Experiment Station has developed a modified elutriate test that simulates contaminant release into effluent from upland disposal sites (Palermo, 1988). The quality of rainfall-induced runoff from upland disposal sites is an additional concern. A laboratory test has been developed under the FVP that exposes sediment samples to simulated rainfall (Skogerboe *et al.*, 1987). Leachate from upland sites may flow into adjacent aquifers or enter nearby surface waters. The Waterways Experiment Station is investigating the potential use of laboratory leaching tests in combination with predictive models for extrapolating laboratory data to field conditions (Hill *et al.*, 1988).

Toxicity and bioaccumulation assays designed for upland sites have also been developed by the Waterways Experiment Station. The uptake of contaminants by plants at upland sites is a possible route of contaminant entry into the food chain. Under the LEDO Program, the Waterways Experiment Station has developed a bioassay that measures the accumulation of contaminants and phytotoxicity in specified wetland plant species (Folsom *et al.*, 1981). Another laboratory assay developed under the LEDO Program measures the uptake of trace elements by plants from an organic extract of dredged sediment. These plant bioassays were verified under field conditions in the FVP (Folsom *et al.*, 1988). Lastly, the potential for the uptake of contaminants by invertebrates can be assessed using an earthworm bioassay. Toxicity and bioaccumulation are monitored over a 28-day period (Lee and Peddicord, 1988). A field trial of this assay was conducted in the FVP (Folsom *et al.*, 1988).

B. LOCAL POLICIES

Most of the sediment dredged in the Delta has been disposed in contained upland sites. As mentioned in Section III, the regulatory authority of the USCOE does not extend to such areas; consequently, the CVRWQCB is the lead agency regulating the possible effects of dredging and upland disposal on Delta waters. The SFBRWQCB has similar authority over the effects of land disposal on Bay waters. The following discussion of local policies regarding upland disposal of dredged material focuses on the Delta, where upland disposal of material from the Bay has recently received a great deal of attention. Upland disposal of contaminated and/or marine sediments in the Delta is regulated pursuant to the California Code of Regulations, Title 23, Chapter 3, Subchapter 15 (Subchapter 15), pertaining to discharges of waste to land. Upland disposal projects may result in discharges to surface or groundwaters and therefore must also comply with water quality requirements expressed in the CVRWQCB's Basin Plan.

Most of the dredging in the Delta has been performed in the Sacramento River and Stockton Deep Water Ship Channels. Testing requirements imposed for a planned deepening of the Sacramento River Deep Water Ship Channel are described below as an example of current policies of the the CVRWQCB regarding this type of project. The Sacramento Channel project will remove over 8 million yd^3 (6.1 million m^3) of sediment from a 69-km length of the Sacramento River, Cache Slough, and the deep water channel to improve navigation (CVRWQCB, 1988). Most of the dredged sediment will be transported by pipeline to any one of 12 land disposal sites. A small amount of the material may also be used for habitat enhancement on Lower Sherman Island.

Modified elutriate tests and bulk sediment chemical analyses were conducted by the Sacramento District of the USCOE during an initial environmental impact assessment of the Sacramento Channel project (USCOE, 1987c). Table 22 lists the contaminants analyzed. Results of these tests were reviewed by the CVRWQCB in the process of water quality certification. The CVRWQCB also issued Waste Discharge Requirements (Table 22) for chemical analyses of receiving waters during dredging and for deposited sediment, disposal site return water, and disposal site receiving water after dredging (CVRWQCB, 1988). Sediment samples were to be characterized using a modified Waste Extraction Test (utilizing deionized water as an extractant), a procedure outlined in Title 22 of the *California Water Code* for "hazardous" levels of contaminants. The Waste Discharge Requirements for this project included numeric limits on the allowable concentrations of trace elements and other standard parameters and required the institution of an effluent toxicity monitoring program (CVRWQCB, 1988).

The CVRWQCB is also the lead agency regulating other types of upland disposal activities, such as the recently proposed placement of 440,000 yd^3 (340,000 m^3) of sediment dredged from Oakland Harbor behind levees on Delta islands (Port of Oakland, 1989). Several types of tests were conducted in the recent evaluation of the potential effects of disposal of the Oakland Harbor material on land:

(i) bulk chemical testing to determine total concentrations of contaminants;

Table 22. Parameters analyzed prior to the Sacramento River Deep-Water Ship Channel project (USCOE, 1987c) and monitoring requirements during and after the project (CVRWQCB, 1988).

	Pre-project		During Project	Post-Project		
Parameter	Sediment	Modified Elutriate	Receiving Water	Spoil Sediment	Return Water	Receiving Water
Silver	X	X	X	X	X	X
Arsenic	X	X	X	X	X	X
Cadmium	X	X	X	X	X	X
Chromium VI	X	X	X	X	X	X
Copper	X	X	X	X	X	X
Mercury	X	X	X	X	X	X
Nickel	X	X	X	X	X	X
Lead	X	X	X	X	X	X
Selenium	X	X	X	X	X	X
Zinc	X	X	X	X	X	X
Tributyl Tin			X		X	X
THM Formation Potential			X		X	X
Organochlorines (EPA Method 608)		X			X	
Organophosphates (EPA Method 614)		X				
Phenoxy Herbicides (EPA Method 615)		X				
Triazines (EPA Method 619)		X				
Carbamate & Urea Pesticides (EPA Method 632)		X				
Dissolved Oxygen			X		X	X
pH			X		X	X
Suspended Matter			X		X	X
Nitrate			X		X	X
Turbidity			X			X
Settleable Matter			X		X	X
Oil and Grease			X		X	X

(ii) chemical analysis of interstitial pore water;
(iii) the modified Title 22 Waste Extraction Test using both a citrate buffer and pH adjusted deionized water as extractants; and
(iv) acute and chronic toxicity tests of simulated effluent.

Bulk chemistry and Waste Extraction tests have been performed on reduced and oxidized Oakland Harbor sediments in an effort to determine the long-term release of contaminants. Pursuant to Subchapter 15, the Port of Oakland has been required to submit numerous plans and reports in preparation of a "report of waste discharge." Waste discharge requirements for this project are likely to include 1) specifications, provisions, prohibitions, and limitations for disposal of the dredged material and for the protection of surface water and ground water quality in proximity to the disposal site and 2) an extensive monitoring program consisting of monitoring of chemical constituents in surface and ground water, acute and chronic toxicity testing, bioaccumulation studies, and other types of monitoring. Since the Oakland Harbor proposal is the first of its kind reviewed by the CVRWQCB, testing requirements for this type of project are still evolving (Peter Haase, CVRWQCB, personal communication).

4. Summary

The scheme recently developed by the Waterways Experiment Station for evaluating potential ecological effects of dredged material disposal in inland waters (the Federal Standard) provides a flexible framework in which the testing required under USEPA regulations (USEPA, 1980) can be performed in a cost-effective manner. However, this testing scheme, particularly the interpretation of results obtained from the required tests, relies heavily on subjective judgement. The development of objective criteria to be used in determining both the need for further testing and the ecological significance of test results would improve this scheme. Establishing such criteria will require professional judgement and will be an iterative process as new data become available. The existence of such criteria would allow for more consistent application of regulations and provide a systematic forum for discussing the potential impacts of dredging and disposal operations. Efforts are being made to develop numeric sediment quality criteria. Controversial aspects of the testing procedures for dredged material disposal into inland waters include the use of the disposal site as a reference site, the use of test organisms that may be relatively insensitive, the lack of sublethal testing, and the application of the mixing zone concept.

The testing scheme for inland waters is essentially similar to the framework that has been used to assess the effects of ocean disposal for over a decade. The ocean testing framework, however, requires detailed evaluation of toxicity and bioaccumulation in all instances where there is considered to be a potential for contaminant-related effects. In addition, firmer guidance for the interpretation of biological tests is offered in the Ocean Implementation Manual.

The ultimate effectiveness of the testing schemes for both aquatic and upland disposal depends on their ability to identify and predict, with accuracy, the potential environmental effects of dredged material disposal. As discussed above, laboratory

tests are not precise predictors of potential effects in the aquatic environment (USEPA/USCOE, 1977; Engler *et al.*, 1988a). One step toward improving this situation would be an increased emphasis on measurement of bioaccumulation in the field, where the complex variation of environmental parameters that affect contaminant uptake are incorporated into the experimental design. Field studies of bioaccumulation of contaminants released from dredged material are discussed in detail in Section V.D.2.

VI. FUTURE TRENDS, MANAGEMENT OPTIONS, AND GAPS IN KNOWLEDGE

A. INTRODUCTION

Future dredging requirements for the San Francisco Bay and Delta are uncertain, due to a lack of firm data upon which to base future estimates. For example, future requirements for maintenance dredging rely heavily on physical factors such as sedimentation rate, rainfall, and runoff, and the seasonal timing of water diversions (Krone, 1979). Future new work dredging estimates are complicated by the availability of funding, agency approvals, public opinion, public policy, and the extent to which access for deep-draft vessels will be expanded at ports in the Bay-Delta region.

Past experience shows that new work projects cause great temporal variability in the total quantities of material dredged and disposed each year. One recent project, the deepening of the John F. Baldwin Ship Channel at Richmond Outer Harbor, illustrates this point well. Phase II of the John F. Baldwin project involved deepening the Channel in Richmond Outer Harbor and enlarging a maneuvering area. During this project (1985-1986), 7.5 million yd^3 (5.7 million m^3) of sediment were dredged and disposed at Alcatraz. Annual dredging from this project was equal to the annual average volume of maintenance material disposed at aquatic sites in the Bay (3.6 million yd^3 [2.7 million m^3] yr^{-1}, see Section IV.A. and V.A.). Figure 9 (Section IV.A.) shows the effect of this new work on the long-term trend in disposal at Alcatraz.

B. ESTIMATES OF FUTURE TRENDS

Estimates of future dredging must consider both maintenance and new work dredging by the San Francisco and Sacramento Districts of the USCOE, by the U.S. Navy, and by the various permittees. This Section reviews dredging estimates from each of these sources; estimated total dredging requirements for the USCOE and the U.S. Navy are shown in Table 23 and Fig 38.

1. Projected Dredging in the Bay

A. DREDGING BY THE USCOE

The Construction-Operations Branch of the San Francisco District of the USCOE (USCOE, 1989a) estimated that maintenance dredging requirements for Federal Navigation Projects under their control will average 3,857,500 yd^3 (3.0 million m^3) yr^{-1} over the next 4 yr (i.e., a total of approximately 15 million yd^3 [11.4 million m^3] during the period 1989-1992). Annual estimates are shown in Table 24.

Three new work projects are currently being planned by the San Francisco District of the USCOE. These are 1) the Oakland Inner Harbor Deep Draft Navigation Improvement Project; 2) Phase III of the San Francisco Bay to Stockton (John F. Baldwin) Ship Channel; and 3) the deepening of Richmond Harbor. It is estimated that the approximate total volume to be dredged for these projects is 15 million yd^3 (11.4

Table 23 Estimates of total volumes to be dredged (yd^3) between 1989 and 1992, excluding permitted projects from both USCOE Districts. After USCOE (1989a); USCOE (1989c) and U.S. Navy (1989).

	Project	Volume	Year Project Begins
USCOE San Francisco District	Oakland Harbor, Phase I	440,000	1989
	Oakland Harbor, Phase II	7,000,000	1992
	John F. Baldwin Ship Channel, Phase III	8,000,000	1992
U.S. Navy	Alameda Naval Air Station	420,000	1990
	Hunters Point Naval Shipyard	433,000	1990
	Oakland Naval Supply Center	830,000	1990
USCOE Sacramento District	Sacramento River DWSC	8,500,000	1989

<u>Fig. 38</u>. Projected total dredging from 1989 to 1992. Data from USCOE (1989a), USCOE (1989c), and U.S. Navy (1989).

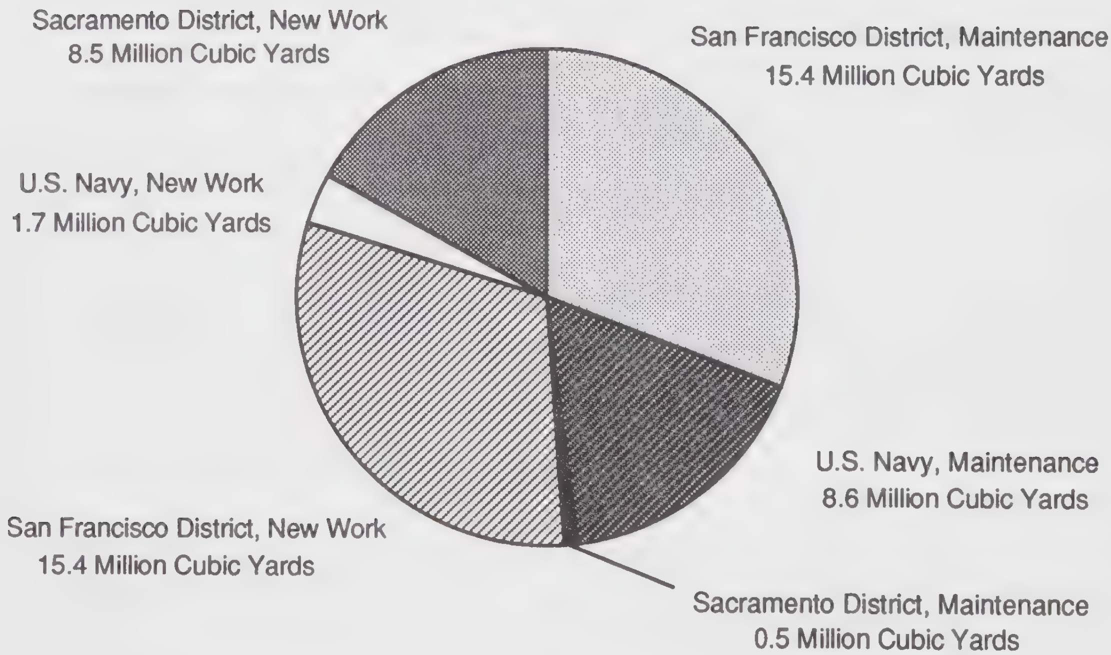


Table 24. Estimates of maintenance dredging by the San Francisco District of the USCOE for the period 1989 to 1992. After USCOE (1989a).

Year	Volume (yd^3)
1989	4,170,000
1990	3,500,000
1991	3,860,000
1992	3,900,000
Total	15,430,000

million m^3) (T. Wakeman, USCOE, personal communication). Table 25 shows the anticipated volumes for each new work project to be undertaken by the San Francisco District, the Sacramento District, and the U.S. Navy in the near future.

The Oakland Harbor Project involves channel deepening, as well as the expansion and/or provision of turning basins in both the Outer and Inner harbors. In Phase I of the project, 440,000 yd^3 (336,000 m^3) of sediment is to be dredged. According to current proposals, most of this material will be disposed on Twitchell Island and Lower Jones Tract in the Delta (Port of Oakland, 1989). Upland disposal of approximately 30,000 yd^3 (23,000 m^3) of contaminated sediment is being considered by USCOE. Work on Phase I began in May of 1988, and approximately 20,000 yd^3 (15,000 m^3) of sediments was dredged before work was halted by litigation brought against the Port by the County of San Mateo.

Phase II of the Oakland Harbor Project, which is expected to begin in 1992, involves the removal of approximately 7 million yd^3 (5.4 million m^3) of sediment. It is anticipated by the USCOE that an ocean disposal site will be designated in time to receive most of the Phase II material. Testing is currently underway to determine the amount of this material that is too contaminated for ocean disposal. The USCOE may propose to place contaminated material upland (T. Wakeman, USCOE, personal communication). Pursuing this option would require the approval of the Regional Boards as well as local health and planning departments.

The San Francisco District, USCOE, is also involved in the San Francisco Bay to Stockton (John F. Baldwin) Ship Channel Project, which has been separated into three phases. Phases I and II (San Francisco Main Ship Channel; Richmond Harbor) have been completed and involved the removal of more than 12.6 million yd^3 (9.6 million m^3) of sediments. Phase III involves the dredging of an additional 8 million yd^3 (6 million m^3) of sediments from the Pinole Shoal Channel and is expected to begin in 1992. The initial authorization of Phase III also included provision for the deepening of the Suisun Bay Channel, which would have involved the removal of a further 2 million yd^3 (1.5 million m^3) of sediments, but cost-benefit considerations have caused this portion of the project to be shelved.

Phase I of the Richmond Harbor Project is also scheduled to occur in 1992, and approximately 1.5 million yd^3 (1.1 million m^3) of sediments will be dredged. Analysis of the sediments to determine suitability for aquatic disposal is underway. A wide range of alternatives for disposal of the dredged material from the Richmond Harbor is being considered, including ocean disposal, aquatic disposal in the Bay, and upland disposal (B. Walls, USCOE, personal communication).

B. DREDGING BY THE U.S. NAVY

Sediment dredged from Navy maintenance projects is disposed on land and at aquatic sites. The Navy presently dredges over 1,600,000 yd^3 (1.2 million m^3) of sediments annually from the Naval facility at Mare Island, 600,000 yd^3 (460,000 m^3) of which is disposed of on land. The balance of sediments dredged, almost 1 million yd^3 (760,000 m^3) annually, is presently disposed at the Carquinez site.

Table 25. New work projects planned for the years 1989-1992 and anticipated volumes to be dredged.

		Volume
Maintenance	San Francisco District	15,430,000
	U.S. Navy	8,622,000
	Sacramento District	1,932,000
New Work	San Francisco District	15,440,000
	U.S. Navy	1,683,000
	Sacramento District	8,500,000
Total		51,607,000

The *U.S. Navy Dredging Plan for San Francisco Bay Area Naval Activities* provides current and anticipated dredging requirements (Table 26) and was supplied by the Environmental Section of the Navy in San Bruno (U.S. Navy, 1989). According to this document, in-bay disposal requirements amount to less than 1 million yd^3 (760,000 m^3) annually for 1988 and 1989; requirements increase to 1.3 million yd^3 (1 million m^3) in 1990 (probably as a result of new work scheduled for that year). The Navy anticipates that total maintenance dredging between 1988 and 1992 will result in approximately 8.6 million yd^3 (6.6 million m^3) of material. Of this total, 5.6 million yd^3 (4.3 million m^3) is planned for disposal at Alcatraz, with the balance disposed on land at Mare Island.

The U.S. Navy Dredging Plan anticipates that three new work (deepening) projects will be undertaken in 1990 (Table 26). These include the Alameda Naval Air Station (419,986 yd^3; 321,000 m^3), Hunters Point (433,000 yd^3; 331,000 m^3), and the Oakland Naval Supply Center (830,050 yd^3; 635,000 m^3), producing a total of nearly 1.7 million yd^3 (1.3 million m^3) of dredged material.

C. DREDGING BY PERMITTEES

As discussed in Section V.A. of this report, dredging by permittees (exclusive of the Navy) during 1986 totalled 1.2 million yd^3 (920,000 m^3) of sediments. In 1987, 1.8 million yd^3 (1.4 million m^3) were dredged under permit. The bulk of this material was disposed at Alcatraz. It is difficult to estimate the future dredging needs of permittees, partly due to an unknown number of outstanding 10-yr permits, but also because reliable records were not kept prior to 1986; hence, no long-term averages may be calculated. Although 10-yr permits are currently being phased out and replaced with 5-yr permits, many older permits remain active. Intermittent dredging on outstanding permits may affect the annual dredging totals of permittees by 10-15% (M. Carlin, SFBRWQCB, personal communication). In the absence of good data, a best estimate would be that annual dredging under permit will continue at a rate similar to that in 1986-87 (1.3 -1.8 million yd^3 [990,000 - 1.4 million m^3]) yr^{-1}.

2. Projected Dredging in the Delta

Maintenance dredging is undertaken by the Sacramento District of the USCOE for two Federal navigation projects: the Sacramento Deep Water Ship Channel and the San Francisco Bay to Stockton (John F. Baldwin) Ship Channel. Although no firm estimates of future maintenance dredging could be obtained, data from operations undertaken in the period from 1975 to 1985 (see Section IV. A. and Appendix 1) suggest that approximately 483,000 yd^3 (370,000 m^3) of sediments will continue to be dredged each year.

New work dredging will be undertaken by the Sacramento District as part of the deepening of the Sacramento Deep Water Ship Channel; the first construction contract is scheduled to be awarded in February 1989 (Table 23). Initially, the project required the removal of 21.5 million yd^3 (16.4 million m^3) of sediments, but this amount has since been scaled down. USCOE (1988e) estimate that approximately 8.5 million

Table 26. Estimates by the U.S. Navy (yd^3 sediment) for maintenance dredging from 1988 to 1992. After the U.S. Navy (1989).

Year	*Total Volume*	*In-Bay Disposal*	*Upland Disposal*
1988	1,574,172	974,172	600,000
1989	1,402,974	802,974	600,000
1990	1,905,000	1,305,000	600,000
1991	1,995,000	1,395,000	600,000
1992	1,745,000	1,145,000	600,000
Total	8,622,146	5,622,146	3,000,000

yd^3 (6.5 million m^3) of material will be dredged from the channel and disposed of on 10 km^2 of land. This project will result in temporary habitat losses of 8 km^2 of agricultural land, 4.7 km^2 of grassland, and 0.8 km^2 of woodland habitat on Grand Island (USCOE, 1988f). As mitigation, 500,000 yd^3 (380,000 m^3) of dredged material from the project may be placed in a shallow lake on Lower Sherman Island to create wetland.

Few data are available from the Sacramento District on dredging activities conducted under permit. As discussed in Section IV A, dredging performed by the Reclamation Districts is loosely controlled, and there are apparently fewer than 10 permits issued annually in the Delta (A. Champ, USCOE, personal communication). The volume of sediment dredged by these permittees is unknown.

C. GOALS, ACTIONS AND OPTIONS FOR DREDGING

The Dredging and Waterway Modification Subcommittee has developed lists of goals and management options related to dredging. These lists have evolved over time, through the various drafts of this report. The full list of goals, actions and options is presented in Appendix 4. "Short term" actions are those that should be implemented immediately rather than waiting for the SFEP Comprehensive Conservation and Management Plan (to be completed in 1992). The recommended short-term actions include (but are restricted to) a request for increased coordination of management activities among agencies, development of a long-term, Estuary wide management plan for dredged material and increased efforts to secure adequate funding for needed research on problems related to dredging and dredged material disposal. The full list of short-term actions is included in Appendix 4.

Unlike the short-term management actions, long-term options represent an array of potential tasks that the Estuary Project should evaluate as it develops the Comprehensive Conservation and Management Plan. Long-term options include different approaches to managing dredging and dredged material disposal, including (but not limited to) efforts to reduce the overall amount of dredging in the Estuary, minimization of in-Bay disposal, development and designation of a suitable ocean site for disposal of dredged material, evaluating alternative disposal options, and managing the problem of toxic chemicals in dredged sediments. The full list of long-term options is presented in Appendix 4.

D. GAPS IN KNOWLEDGE

This review of the status and trends of dredging and dredged material disposal in the San Francisco Estuary revealed a lack of knowledge in a number of areas critical to a full understanding of the processes that operate during dredging and dredged material disposal, and the effects that dredged material disposal may have on the ecosystem. These "gaps in knowledge" exist as the result of either insufficient data on certain processes and effects (e.g., sediment resuspension and redeposition in the Estuary) or as the result of existing data yielding equivocal results (e.g., effects of turbidity on Estuarine fisheries, and the bioavailability of contaminants associated with disposed dredged material). This section of the report identifies those areas where our lack of knowledge is most critical. Further, this section identifies a number of

suggested topics for research and monitoring that will serve to fill these gaps in knowledge and improve our understanding of the complex relationships that exist between Estuarine function, dredging and dredged material disposal. Such information is important in deciding what short-term actions may be taken now, and establishing reasonable priorities for long-term management options applicable to dredging and dredged material disposal in the Estuary.

1. Dredging Activities

(i) *The precise amounts of dredged material disposed at sites in the Estuary.* How much material is disposed (monthly and annually) at each site in the Estuary? What types of equipment are used in each dredging and disposal operation? What is the frequency of disposal at in-water sites in the Estuary and on land?

(ii) *The quantity of sediment dredged in the Delta and used for levee maintenance.* Is any of this material contaminated? What are the levels of contamination? What are the possible effects?

(iii) *Historical quantities of sediments dredged and disposed in the Estuary.* How well do permitted amounts of dredging coincide with actual quantities dredged and disposed? Is overburden at any given site likely to be less or more contaminated that the permitted sediment? Can useful historical trends be constructed by reviewing past dredging permits? How can this information be used to better elucidate the current status of dredging and waterway modification in the Estuary?

2. Dredged Material Quality: Evaluation and Testing

(i) *The "background patterns" of sediment contamination in the Estuary.* What is the present distribution of contaminants in the sediments of the Estuary? Can any physical characteristics of Bay sediments be correlated with sediment chemical quality? Are there "background" concentrations of contaminants in sediments to which concentrations in dredged material can be compared? Are there regions of the Estuary with "background" concentrations of contamination that can be used for control purposes in experiments?

(ii) *The causal mechanisms of toxicity in sediment bioassays.* Do sediment bioassays depict chemical toxicity? Are factors that covary with contaminant concentrations (e.g., grain size and total organic carbon content) actually causing the toxicity observed in sediment bioassays?

(iii) *What bioassays are appropriate for use in examination of contaminated sediments?* Are acute, lethal bioassays preferable to chronic bioassays as indicators of potential effects? Are there numerical models adequate for representing potential acute or chronic effects (e.g., Sediment Triad, Equilibrium Partitioning)? Which of the many assays currently being tested can be used with confidence? Can any laboratory study adequately represent what results will be in the field? Can data from other parts of the country be transferred directly for use in the Estuary?

(iv) *What sublethal bioassays or endpoints might be suitable for use in evaluating chronic effects?* Are chronic bioassays preferable to acute, lethal assays in assessing the effects of dredged material disposal? Do any existing chronic bioassays hold promise for applicability to the Estuary and its dredged material disposal problems? Are there chronic effects for evaluation that may be more useful, or more sensitive, than the bioassays currently used for evaluating dredged material effects? Are there chronic, sublethal assays that allow the identification of effects due to single toxicants as well as complex mixtures? How can an appropriate suite of chronic assays be developed that will help identify the major contaminants of concern?

(iv) *The ecological significance of test results, including bulk chemistry assays, toxicity bioassays, and bioaccumulation tests.* What is the relationship between laboratory tests of contaminated sediment and the actual effects of disposal of this sediment in the Estuary? What is the relationship of contaminant body burden and effects in the Estuary? Can objective standards be developed for determining the types of tests necessary for contaminated sediments and for classifying sediments on the basis of the results of such tests?

3. The Fate of Disposed Dredged Material

(i) *The mechanism by which the mound of material formed at the Alcatraz disposal site.* How quickly did the mound of material grow? Could the mounding have been slowed or prevented through alternate disposal practices? What is the likelihood of mounding occurring at the other disposal sites?

(ii) *The initial distribution of sediment dispersed from the disposal sites in the Estuary.* Where does material dispersed from the disposal sites go initially? What is the rate and magnitude of sediment transport in the Estuary? In sub-sections of the Estuary? How does the equipment used affect the dispersion of the disposed material? How does the method, timing, and frequency of disposal affect transport (or retention) of dredged material at a given site?

(iii) *The ultimate fate of disposed material in the Estuary.* What fraction of material is redeposited in quiescent areas of the Estuary? What fraction of material is redeposited in artificially maintained channels, slips etc.? How important are factors not yet modeled, such as wind-driven currents, in determining the ultimate fate of disposed material? What fraction of disposed dredged sediment leaves the Estuary; how much material returns to navigation channels?

(iv) *How well do the complex hydrodynamic and sediment transport models available actually represent the the Estuary?* How uncertain are the predictions of these models? How sensitive the predictions to changes in the assumptions used to build the models?

4. The Effects of Dredged Material Disposal

(i) *The fraction of the contaminants in dredged material that is released to the environment during and after disposal.* Can accurate estimates of annual loads of contaminants due to the disposal of dredged material be developed?

(ii) *The bioavailability of the released fraction of contaminants.* How does contaminant bioavailability vary with such factors as season, salinity, or species? How much of the observed bioaccumulation of toxic contaminants in the Estuary is due to the disposal of dredged material? Do existing models for chemical equilibrium in the environment hold any promise for application to dredging problems in the Estuary (e.g., Equilibrium Partitioning; food-chain modeling)?

(iii) *The contribution of dredged material disposal to suspended sediment concentrations in Central Bay.* Does disposal of dredged material at the Alcatraz disposal site significantly increase the suspended sediment concentrations in Central Bay beyond the short time period after disposal? How does frequent (e.g., many times daily) use of the disposal sites affect suspended sediment concentrations in the Estuary?

(iv) *The impact of increases in the concentration of suspended solids from dredging operations on estuarine biota.* Are egg or larval stages of biota in the Estuary adversely affected by increases in suspended solids concentrations? Are the biota affected by particle-associated contaminants? Is there an interaction (i.e., synergism or antagonism) between suspended solids and contaminants and their effects on organisms? Do such increases result in behavioral changes, such as alterations of migratory patterns or avoidance of historical habitat?

(v) *How well do we understand the trophic structure ("food chain relationships") in the Estuary?* Which predators will be affected by changes in the abundance and distribution of invertebrates? Which predators might be expected to be particularly susceptible to accumulation of contaminants from their prey?

E. RECOMMENDED RESEARCH

It is clear that there are significant inadequacies in present knowledge regarding dredging in the San Francisco Estuary, and Section VI.D. (above) lists such "gaps in knowledge". These areas of uncertainty vary in their ease and cost of study and their importance to the management of dredging and waterway modification in the Estuary. The Sub-Committee on Dredging and Waterway Modification has requested that the Aquatic Habitat Institute (AHI) provide its assessment as to which gaps in knowledge must be filled prior to management decisions being made, and which gaps in knowledge can be filled after making management decisions. AHI was contracted for this project because of the scientific expertise and experience of its staff; this assessment is not scientific in nature. Management decisions are political decisions in which scientific information is but one component. Costs and benefits are weighed, including those that can be quantified and those that cannot, and a judgement is made regarding the appropriate course of action. The opportunity costs of decisions, including those that might accrue to future generations, are also considered by decision makers. Scientific information, when conclusive, can be a powerful tool for clarifying the costs and benefits of management decisions.

Little conclusive information of this kind is available regarding the environmental impacts of aquatic disposal of dredged material in the San Francisco Estuary. This is particularly true with respect to two major public concerns (1) the effects of the disposal of contaminated sediments and (2) whether dredged material disposal affects fishing success by increasing suspended sediment concentrations around disposal sites. Regarding the latter issue, available data are not sufficient to support or refute the claims regarding the impact of dredged material disposal upon turbidity and fishing success in the Central Bay. It would be possible to conduct additional research to monitor turbidity in Central Bay during various disposal regimes, tidal stages, and weather conditions that would be likely to provide strong evidence for the importance (or lack thereof) of dredged material disposal to turbidity in Central Bay. The recent decision of the SFBRWQCB to place limits on the disposal of dredged material in the Estuary, however, was taken due to the potential for these effects to occur, demonstrating that regulatory decisions are sometimes made in spite of a lack of conclusive scientific evidence.

The impact of dredged material disposal upon contaminant concentrations in the water column and organisms of the San Francisco Estuary will not be an easy question to answer. It will require carefully designed, well-managed research and monitoring, and it is likely that the cost will be high, and the research will take several years to complete. The results of such studies will clarify the environmental impact of dredged material disposal in the Estuary. Because of the many sources of contamination in the Estuary, it is possible that cessation of in-Bay disposal would have no detectable impact on contaminant burdens in the biota of the Estuary. Conversely, if the many sources of contamination in the Estuary were controlled, and sediments contaminant burdens tended toward a new, lower equilibrium, it is possible that in-Bay disposal of dredged material could be maintained, and contaminant burdens in biota could decline.

The information presented in this report suggests that the aquatic disposal of sediments containing contaminants is contributing to the elevated tissue concentrations of some contaminants in the biota of the San Francisco Estuary. If this is true, and if in-Bay disposal of contaminated sediments were to cease, then body burdens of contaminants in organisms in the Bay might decline. Whether such a decline would be detectable, or significant, with regard to potential sublethal effects of contaminants on organisms, is unclear. This is due to the wide range of variability seen in environmental samples from any location.

Although it is possible to make management decisions regarding contamination in dredged sediments without additional scientific study, there are key scientific and technical issues that could be examined to give decision-makers the best information for policy and management decisions. These issues are described below. As was stated at the beginning of this report (Section II), the inclusion of this list of recommended research should in no way be interpreted by the reader as a statement by the authors that these studies must be completed prior to making management decisions regarding the disposal of dredged material in the San Francisco Estuary.

1. ***The precise amounts of dredged material disposed at sites in the Estuary***. It is recommended that more detailed data be collected and routinely analyzed to provide precise information regarding dredging and disposal activities in the Estuary. This is particularly the case with respect to dredging activities carried out under permit from the USCOE. The San Francisco District of the USCOE has undertaken such efforts in the past few years through the appropriate use of post-dredging bathymetric surveys; these activities should be continued and expanded. It will be important to obtain accurate estimates of amounts of material and temporal trends in disposal, particularly with respect to the frequency of disposal events. It is also recommended that the Sacramento District of the USCOE develop estimates of the quantities of sediment dredged by Reclamation Districts under their jurisdiction in the Delta (i.e., for levee maintenance and repair) and examine the quality of these sediments.

We also recommend that the frequency of disposal activity should be recorded at all sites. Records should include the date and time of disposal, the volume of material disposed, the source of material that was dredged, the type of equipment disposing, and tidal stage. The USCOE San Francisco District has recently begun to accumulate "instantaneous" FAX records of disposal activities at Alcatraz; these records may well prove to be of inestimable value at such time that suspended sediment sampling is going on at the site, or in reference to particular observations regarding water quality in the vicinity of the site.

2. ***The ecological significance of test results, including bulk chemistry assays, toxicity bioassays, and bioaccumulation tests***. The precise relationship between laboratory tests using contaminated sediment and the actual effects resulting from disposal of this sediment in the Estuary will probably never be determined. This is due to difficulties in conducting controlled field experiments, where numerous factors influence contaminant release, bioavailability, and toxic effects under field conditions. Laboratory studies can, however, provide useful

information, particularly for testing "worst case" conditions. It is recommended that regulatory agencies endeavor to develop a more objective method by which the results of sediment testing can be evaluated. This will involve the establishment of criteria that quantitatively define the point at which a sediment must be subjected to biological and chemical tests and that define when test results are to be considered significant in predicting an adverse effect upon disposal. Establishing such criteria will require professional judgement, and will be an iterative process as new data become available. The existence of such criteria would allow for more consistent application of regulations and provide a systematic forum for discussing the potential impacts of dredging and disposal operations.

Studies should also be undertaken to investigate the causal mechanism of the toxic responses observed in sediment bioassays. Particular attention must be given the role of sediment grain-size and total organic carbon concentrations, as these factors covary with contaminant concentrations and confound the interpretation of bioassay results.

3. ***The ultimate fate of disposed material in the Estuary.*** Knowledge of the fate of disposed material is vital to understanding the transport of disposed sediments throughout the Estuary (including back to navigation channels), and the consequent distribution of the contaminants associated with dredged material. This topic can be investigated using both models and tracer studies.

(i) It is recommended that the modeling effort currently underway by the USCOE be continued, with a clear focus upon circumventing several key limitations. Field data from the San Francisco Estuary must be made available to verify that the models can accurately represent (over appropriate periods) the complex phenomena that contribute to sediment transport. These include the effects of winds and the vertical stratification of currents. The sensitivity of the models to key parameters (including boundary conditions) should be documented. It is considered essential that estimates of uncertainty be included with model predictions, particularly if modeling data are to be used for assessing the effects of alternative management strategies.

(ii) It is also recommended that tracer studies be conducted to define the short- and long-term transport of suspended particles from estuarine disposal sites. These studies could provide information regarding the return of disposed material to navigation channels, the dispersion of disposed material under different hydrological regimes, and the possible contribution of dredged material disposal to "hot spot" formation in the Estuary. New highly sensitive and economical tracing techniques utilizing biological tracers (bacteriophages) are now available and could provide much-needed information regarding sediment transport in the Estuary.

4. ***The bioavailability of contaminants released by disposal of dredged material.*** Data regarding the bioavailability of contaminants released from dredged material is essential to determine the potential for toxicological effects due to the bioaccumulation of contaminants. It is recommended that a routine biomonitoring program be established at aquatic disposal sites in the Estuary. This program should

utilize the California mussel (*Mytilus californianus*) and follow the established procedures for the use of biomonitors (see Phillips, 1980, 1988). This program should be coordinated with the implementation of a local and regional biomonitoring program as recommended by Phillips (1988).

5. ***The spatial and temporal trends in suspended solids concentrations at disposal sites.*** It is recommended that the concentration of suspended solids be monitored throughout the water column at the disposal sites in the Estuary, with an emphasis on understanding the contribution of dredged material disposal to suspended sediment concentrations. In particular, the suspended sediment concentrations in the Central Bay during periods of frequent use of the Alcatraz disposal site should be documented.

6. ***The impact of suspended solids from dredging operations on sensitive life-stages of estuarine biota.*** It is recommended that additional laboratory studies be conducted to improve our ability to predict the impact of suspended sediments upon sensitive life stages of resident species that could be exposed to sediment plumes from dredging and disposal operations. Commercially important species should be emphasized in such studies, and experiments should be designed to simulate field conditions to the maximum possible extent. Such studies should concentrate not only on lethality, but also on the development of sensitive assays useful in estimating the potential for organisms to survive, grow, and reproduce under prevailing conditions in the test aquarium.

PART TWO:

WATERWAY MODIFICATION

by

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I. INTRODUCTION

Within the last century, human activities have drastically altered the physical character of the San Francisco Estuary. Estuarine intertidal wetlands are formed where a delicate balance of competing processes - sedimentation, erosion, sea-level rise, and tidal inundation - create areas suitable for colonization by wetland vegetation. Approximately 95% of the former intertidal wetlands were "reclaimed," primarily for agriculture, but also for salt ponds, duck clubs, and urban development. Man has intervened in this dynamic equilibrium and is inevitably committed as a permanent manager dedicated to influencing these physical processes through waterway and shoreline modifications to protect economic activities and the Estuarine environment.

Two processes that can have major adverse effects on the economy and environment are coastal flooding and shoreline erosion. Most of the "reclaimed" wetlands are protected against flooding by levees. The land surface has subsided, particularly in the Delta, where peat wetland soils have oxidized and lowered land levels more than 6 m. For most agricultural areas, levees are inadequate; around urbanized areas, protection against coastal flooding is of variable quality. The consequences of flooding go far beyond immediate economic damages; in the case of the Delta islands, inundation can alter the hydrodynamics of the Estuary, affecting the Estuarine ecosystem and the quality of water diverted from the Delta.

The process of shoreline erosion is both affecting and being affected by human activities. In some areas, the integrity of levees is directly threatened. In other areas, erosion is reducing the extent of some of the last remnants of natural tidal marsh around the margin of the Bay.

The next section of this report provides an overview of the present management of coastal flooding and shoreline erosion, highlighting areas where research and data collection would aid in better management decisions.

II. EXISTING MANAGEMENT STRUCTURE

Although no single agency has responsibility for coordinating flood protection planning or shoreline protection, the following Federal and State agencies have responsibilities in portions of the Estuary:

(i) U.S. Army Corps of Engineers, Sacramento District: Provides design and construction assistance to local flood control projects, provides for the dredging of navigational channels, and establishes operating criteria for flood control reservoirs in the Central Valley.

(ii) U.S. Army Corps of Engineers, San Francisco District: Provides design and construction assistance to local flood control projects west of the Delta, as well as floodplain management services.

(iii) Federal Emergency Management Agency: Through its Flood Insurance Program, this Agency identifies flood hazard zones in each community and regulates floodplain development via flood insurance rates and oversight of local government floodplain regulations.

(iv) California Department of Water Resources: This organization has responsibility for flood management and operation of flood control facilities in the Central Valley, and is involved with planning for flood protection in the Delta.

(v) California Reclamation Board: Although staffed by DWR, the Reclamation Board is a separate organization with responsibility for regulating channel and levee modifications in the Central Valley and Delta.

(vi) Bay Conservation and Development Commission (BCDC): Within its area of jurisdiction, BCDC has established flood protection standards for new permit applications, and also reviews and permits erosion protection works.

III: HISTORICAL TRENDS

A. THE EVOLUTION OF THE ESTUARY

The San Francisco Estuary was formed during the last 10,000 yr, when a rapid rise in sea level following the last Ice Age (amounting to about 2 cm yr^{-1}) inundated the alluvial valley of the Sacramento River (Atwater, 1979). By about 6,000 yr ago, the rate of rise slowed to about 0.2 cm yr^{-1}, roughly the same rate at which it has been measured in the last 130 yr. Nevertheless, in the last 6,000 yr, the tidal Estuary continued to expand in area, reaching nearly to Sacramento (see Fig. 38).

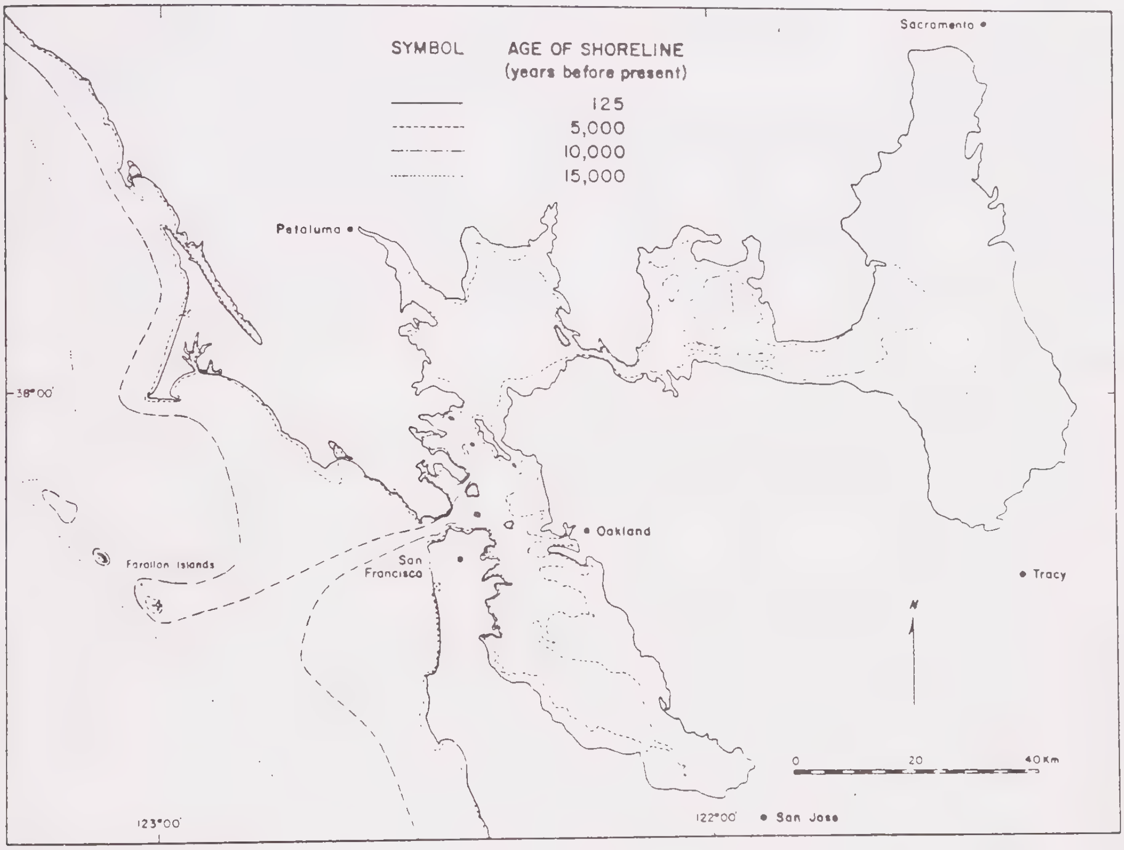
During the period of slower sea-level rise, extensive marsh plains of wetlands were able to establish themselves around the margins of the Estuary. In the Delta, the vigorous growth of tules (*Scirpus* spp.) was able to keep pace with rising sea level, creating peat beds up to 18 m thick in the western Delta. In the lower part of the Estuary, extensive pickleweed (*Salicornia pacifica*) marsh plains developed, first as a narrow shoreline fringe, then extending inland as sea level rose. These salt marsh plains were formed wherever there was protection against wave action. Initially, cordgrass (*Spartina foliosa*) established itself on the mudflats, allowing sediment to accumulate, and raising the elevation to that suitable for colonization by pickleweed. Eventually, the marsh plain elevation reached an equilibrium at or slightly above mean higher high water (MHHW) (Atwater *et al.*, 1979). As the marsh plains were formed, a tidal drainage system of slough channels developed, the geometry of which was dictated by the tidal prism (the volume of water moving in and out on each tide).

B. GEOMORPHIC PROCESSES

In the natural state, most of the sediments discharged into San Francisco Bay were conveyed by infrequent large flood flows on the Sacramento River. As they flowed south through the Sacramento Valley, the Sacramento and Feather Rivers built up natural levees of coarser sediments deposited during high floods. These levees created large "basins" on the Valley floor that supported extensive tule marshes (Division of Water Resources, 1955). The natural levees of the Sacramento River extended downstream as far as Brown's Island, forming a "crow's foot" delta of distributory channels similar to the Mississippi River mouth. In contrast to the delta of the Sacramento River, the delta of the San Joaquin River had no natural levees because the river channel merged directly into tidal sloughs. The large natural basins on the Sacramento Valley floor acted as flood storage reservoirs during high flood flows. They reduced the peak flood flows, and because sediment transport rates are exponentially proportional to flow velocity, they also reduced sediment discharge.

During floods, positive downstream river flow would extend into Suisun Bay; larger floods would extend into San Pablo Bay and occasionally the Central Bay. Most of the coarser sediments and sands comprising the bedload were therefore deposited in the upper Bays. It is unlikely that more than a small portion of this material was discharged directly out of the Golden Gate during floods, although it is possible that subsequent tidal scouring could have caused a significant fraction to be discharged to the ocean over a long period.

Fig. 38 Approximate high-tide shorelines near San Francisco during the past 15,000 yr. The 125-year-old shoreline denotes the landward edge of tidal marshes before human encroachment to or, where no marsh was present, the high water line *circa* 1850. Locations of older shorelines are estimated by projecting sea levels of the past 15,000 yr onto the land surface inundated by the growing Estuary during this time. After Atwater (1979)



At least 90% of the sediments discharged to the Estuary were fine silts and clays carried in suspension (USGS, 1980). On encountering salt water (salinities of about 1 to 2 ‰), the clays flocculated, increasing their settling rates (Krone, 1974). Much of these finer materials were deposited in the shallows of San Pablo and Suisun Bays; during large floods, a fraction would be discharged out the Golden Gate. Subsequent wave erosion, particularly during the summer, resuspended the sediment, which could then be distributed throughout the Estuary via tidal currents and the Estuarine circulation (see Part I, Section V.C., for a more in depth description of sediment transport).

The morphology of the Estuary has been dictated by the dynamic equilibrium between deposition of resuspended sediment and scouring due to wave action and tidal currents. The depth of the shallows and mudflats that form most of the area of the Estuary is dictated by the intensity of wave action, which in turn depends on the fetch of the predominant wind directions (usually west to northwest in the summer and southeast in the winter). The deeper channels running through each of the bays have been formed by tidal scouring. As the strength of the tidal current is mainly influenced by the tidal prism upstream, the depth and width of the deeper channels decreases inland. The size of slough channels in the marshplains around the Estuary margin and in the Delta was similarly dictated by the tidal prism of the marsh area it drained.

C. HYDROLOGY AND FLOODING

Most of the freshwater flowing into the Estuary occurs as runoff from the Central Valley. Typically, the natural inflow hydrograph would have had two peaks, one in winter, due to winter rainstorms and the other in the spring due to snowmelt (DWR, 1987b). Peak river flows in the winter were usually higher than spring flows, but of shorter duration. It is these peak winter flows that probably conveyed the most sediment into the Estuary (Porterfield, 1961). Local runoff from the watershed draining directly into the Bay occurred in response to winter rainstorms. The amount of sediment discharged by peak flows from these local drainages is very small in comparison with the input from the Sacramento River, and not significant in affecting the Estuary morphology (USGS, 1980).

In its natural state, the Estuary was susceptible to flooding from winter flood flows and high tides. Infrequent high flood flows on the Sacramento River would rise until they overtopped the natural levees, filling the floodplain basins. Further downstream, overflow of the Sacramento levees would tend to inundate the tidal marshes in the San Joaquin Delta, but probably by not more than a few feet due to the large storage volume (Thompson, 1982). Flood flows on smaller streams discharging directly to the Bay would tend to dissipate in the lower reaches of the creeks. Many of the smaller creeks did not discharge directly to the Bay but terminated in freshwater/riparian wetlands on the Bay margin.

Extreme tides caused by storm surges superimposed on spring tides could elevate water levels up to about 1 m above the marshplain level for several hours. The most extreme conditions probably occurred during periodic *El Nino*-related seasonal elevations in sea level off the North American Pacific Coast (Flick, 1986).

D. HISTORICAL WATERWAY MODIFICATIONS

The natural hydrology of the Estuary has been affected greatly by human activities. One opinion has been expressed that approximately half of the average annual inflow is being diverted, primarily for agriculture in the San Joaquin Valley (Williams and Fishbain, 1987). Water diversion cannot be expressed, simply, as a portion of flow; rather, diversion, and its effects, have to be evaluated on a seasonal basis. The many large multi-purpose storage reservoirs built on all the major Central Valley rivers capture most of the spring snowmelt runoff; their flood control operation during the winter reduces peak flood discharges into the Estuary, but only slightly reduces the total volume of winter rain flood discharges (DWR, 1987c).

Most of the Sacramento Valley floodplain is now used for farming and is protected against flooding by a system of levees and bypass channels known as the Sacramento Valley Flood Control Project. The loss of floodplain storage and the increased hydraulic efficiency of the channel system has probably tended to increase peak winter rain flood discharges into the Estuary (thereby reducing spring and summer flows). The net effect of all the man-made modifications to the drainage system on winter flood discharges to the Estuary has not been systematically analyzed. Except in very large infrequent floods, it is likely that peak discharges have been decreased (Williams and Vorster, 1987).

Many of the smaller streams discharging directly to the Bay have also been modified. Urbanization of the watersheds and channelization of creeks tend to increase downstream flood peaks. In urban areas, most of these drainages now have artificially-maintained channels in their lower reaches, so that flood waters can discharge directly to the Bay.

Sediment inputs to the Estuary have periodically increased due to human activities. Hydraulic mining in the 19th century greatly increased suspended sediment concentrations. The reclamation of floodplain wetlands and tidal wetlands in the Delta and elsewhere in the Estuary eliminated natural sediment traps. Accelerated erosion in the watersheds due to logging, grazing, and farming also increased suspended sediment load discharging to the Estuary. After hydraulic mining was banned in the late 19th century, sediment inputs to the Estuary gradually declined. No recent sediment budget analysis has been calculated for the Estuary, but further declines in sediment input due to dam construction and diversion of freshwater inflows are predicted (Krone, 1979).

Human activities have had a dramatic effect on the morphology of the Estuary in the last century. Almost all of the natural tidal marshes have been leveed for agriculture, duck clubs, salt ponds, or urban use. This has reduced the tidally-influenced area by 60% (Atwater *et al.*, 1979). The loss of tidal prism in reclaimed marshes has caused most of the remaining major slough channels to silt up, requiring maintenance dredging to maintain safe navigation.

The historical increase in sediment loads had a substantial effect on mudflat and subtidal areas of the Estuary. The deposition of fine sediments from hydraulic mining raised elevations a few meters. It appears that over the last century this "mud

wave" has migrated from Suisun to San Pablo to Central Bay, it remains unclear whether its effect has now been dissipated (Krone, 1979).

The virtual elimination of tidal marshes as sediment "sinks", combined with increased sediment inputs to the Estuary, have probably increased suspended sediment concentrations in the water column of the Bay above historical levels. Mudflats and shallow water areas store the sediment at slack and calm-water periods, but wave action later resuspends many of these sediments. The volume of sediment recycled in this fashion is much larger than the volumes discharged into or out of the Estuary (Krone, 1979). Increased suspended sediment concentrations have led to the formation of small areas of new tidal marsh on the outboard side of levees, or in locations where fill protected mudflats against wave action.

IV. CURRENT STATUS

A. GENERAL

The area at risk due to coastal flooding can be defined as the area whose flood hazard is influenced by high tidal stages in the Estuary. For the Bay area, this accounts for roughly 90% of the total flood-prone area (Limerinos *et al.*, 1973). Low-lying flat land around the perimeter of the Estuary has attracted a variety of high-value urban uses, including industrial facilities, residential areas, airports, dock facilities, and sewage treatment plants. However, most of the area at risk consists of nonurban uses: agriculture in the Delta, salt ponds in the South and San Pablo Bay, and duck clubs in Suisun Bay.

Much of the flood-prone area is located on the former tidal marshes, although adjacent upland areas are affected by backwater effects of coincident flood flows and high tides. In addition, some former upland areas have subsided due to groundwater pumping (e.g., South Bay; Fig. 39) and gas extraction (e.g., Delta), placing these areas within the influence of high tidal stages.

Originally, the tidal marshes would have been at elevations approximately +1 - +1.3 m above MHHW . National Geodetic Vertical Datum (NGVD). However, within a few years of reclamation, the marsh soils subside as they dry out, typically lowering in elevation 0.6-1.3 m. Where the marshplains were mainly peat, as occurs in the western Delta, oxidation also occurs as land is tilled. Net subsidence of the land surface can be as high as 7.5 cm yr^{-1} (DWR 1980), and some of the western Delta islands are now more than 6 m lower than historic levels.

All the low-lying areas depend on both levees and artificial internal drainage systems to protect against flooding. The level of protection varies considerably for different areas throughout the Estuary. Flooding can occur from high tides and from high flood flows independently. The most critical conditions occur when high flood flows coincide with high tides. Then both components of the flood control system can fail. Failure modes are summarized in Fig. 40.

B. LEVEE FAILURE

Few of the perimeter levees around the Estuary are properly engineered structures. Even levees protecting urban areas may be *ad hoc* berms placed by farmers 100 yr ago using material side-cast from a ditch. In the Delta, most of the levees are poorly constructed, consisting of mixtures of sand, silt, and peat. The most stable levees in the area are the Sacramento Valley Flood Control Project levees constructed on the natural levees along the Sacramento River.

The consequences and costs of failure of levees of the Delta islands could be significantly greater than the loss of the inundated farmland itself. It has been suggested that there might be a significant effect on the morphology and hydrodynamics of the Estuary if a few key Delta islands were allowed to revert to tidal action. Under such circumstances increases in the tidal prism could cause the salinity

Fig. 39. Land subsidence from 1934 to 1967 in the Santa Clara Valley, California. After BCDC (1987).

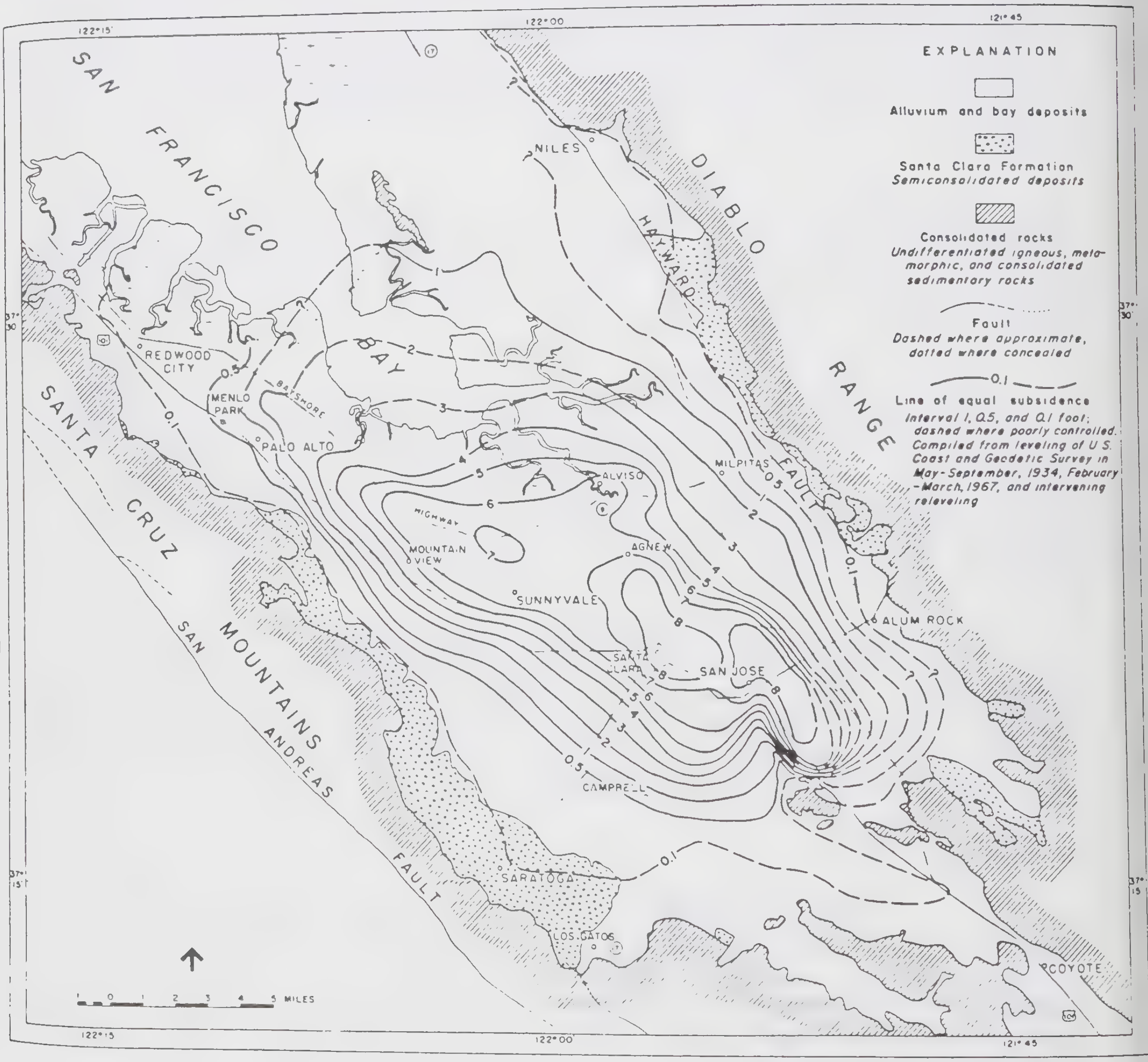
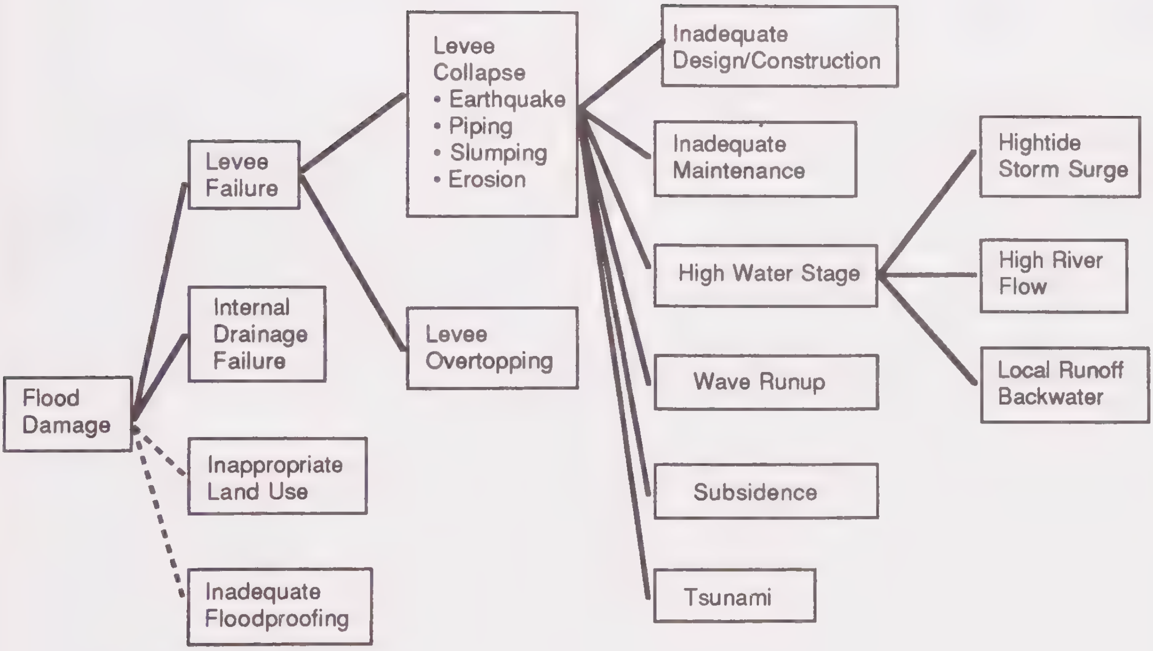


Fig. 40. Failure modes for coastal flood protection systems.



to change, affecting the quality of water diversions (Williams, 1988) and the functioning of the Estuarine ecosystem. In addition, utility lines and communications could be affected. Other effects would be more subtle, such as reduction in sediment delivery to the Bay due to trapping of sediment in the Delta. These are potential effects, however, and it must be stressed that the tidal prism is also affected by the constrictions at the Carquinez Straits and at Chipps Island.

While DWR is presently developing plans to upgrade levees on Sherman Island and in the North Delta (DWR, 1988a, 1988b), there is no comprehensive program under way to upgrade all levees to the acceptable design standards described by DWR (Bulletin 192-82, 1982). The estimated cost of such a program ($4 billion in 1982) is probably prohibitive. However, no systematic analysis of the possible management options for the entire Delta is presently being carried out either on the technical or management level.

Future high water levels will depend on the rate of sea level rise, which will be influenced by climatic changes and the degree of land subsidence. Predictions of climate change for California indicate increases in winter runoff, with consequent increases in magnitude and frequency of winter flood flows (Gleick 1988). Mid-range estimates of rise in sea level of approximately 1 m over the next century would greatly increase risk and frequency of coastal flooding (Williams 1988). Such estimates have wide ranges, however, and the overall rate of sea level rise in the next century is subject to debate. The potential area affected is shown in Fig. 41. Even without considering climatic changes, a continuation of the historic rate of rise would increase sea levels by 20 cm over the next century (BCDC, 1987).

Levee failure can occur due to collapse or overtopping. Collapse can occur due to liquefaction and slumping during an earthquake, from bank erosion and bank slumping, or due to excessive seepage from pipes eroding the levee interior. Overtopping may occur during periods of high water. The poor construction of most of the Delta levees makes them particularly susceptible to seismic failure. Most of the levees around the Estuary are at risk because of the numerous faults in the area (Fig. 42). The earthquake of 1906 occurred prior to the reclamation of many of the tidal marshes, and at a time when Delta levees in place were considerably smaller than there are now (DWR, 1980). Prior to 1972, active faults were assumed not to exist in the Delta. Investigation of minor earthquakes in the last decade has shown, however, that drainage and levee failure are directly correlated with earthquakes (Finch, 1985). A major earthquake, such as that experienced on 17 October 1989, has the potential of causing simultaneous levee failure and flooding of large areas of the Delta. This would draw in saline water from downstream and could cause a shutdown of export pumping from the Delta. However, we are unaware of any data or observations suggesting that the earthquake of 1989 resulted in any levee failure.

The risk of levee failure due to leakage of piping and slumping is largely dependent on the materials used in constructing the levee, the levee cross-section, its maintenance, and the height and duration of high water. Delta levees are particularly susceptible to these types of failure because of their heterogeneous composition, their narrow cross-section, subsidence of the land surface, and their generally poor

Fig. 41. Maximum area potentially affected by 100-year high tide with 1 meter sea level rise. After Williams (1988)

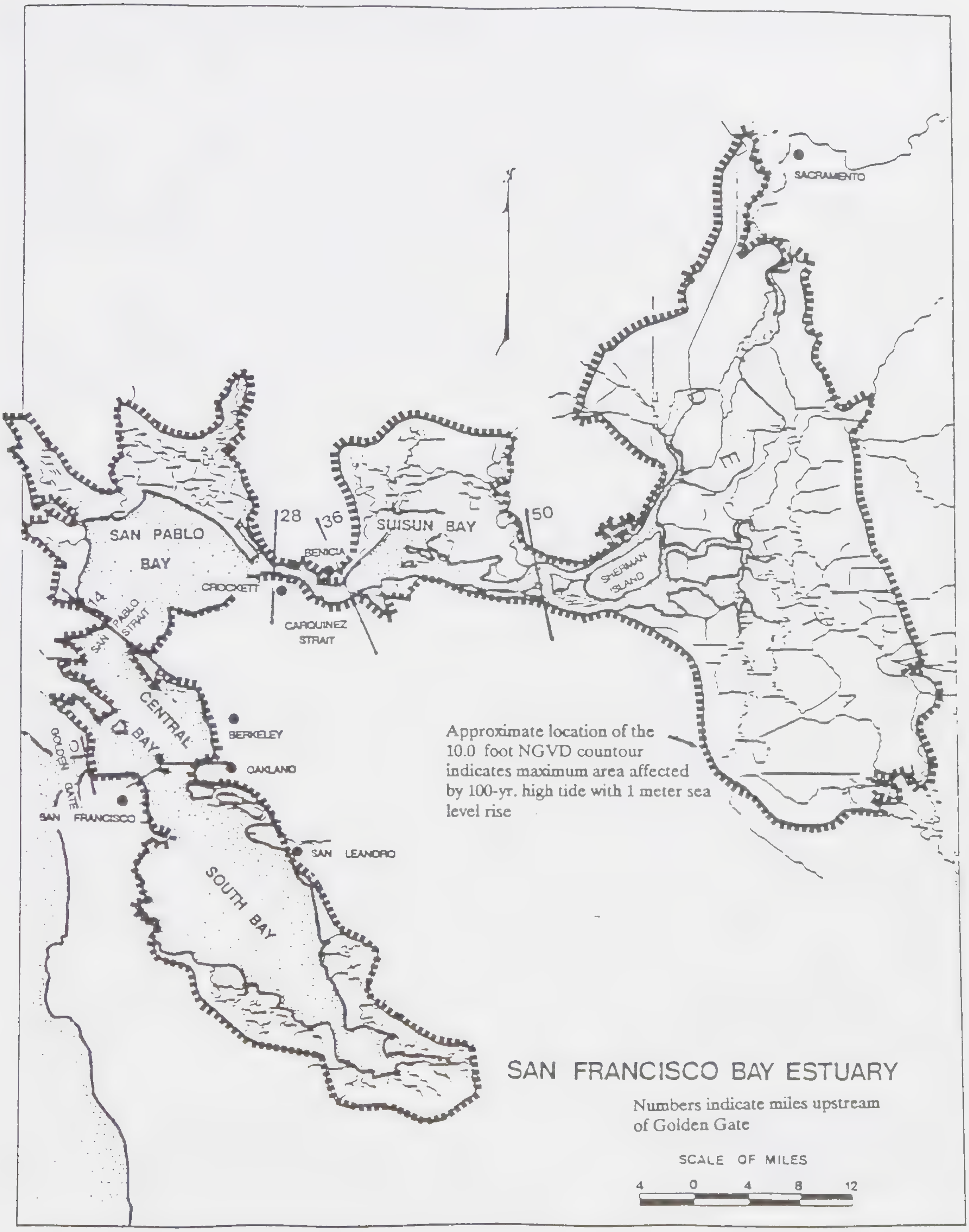
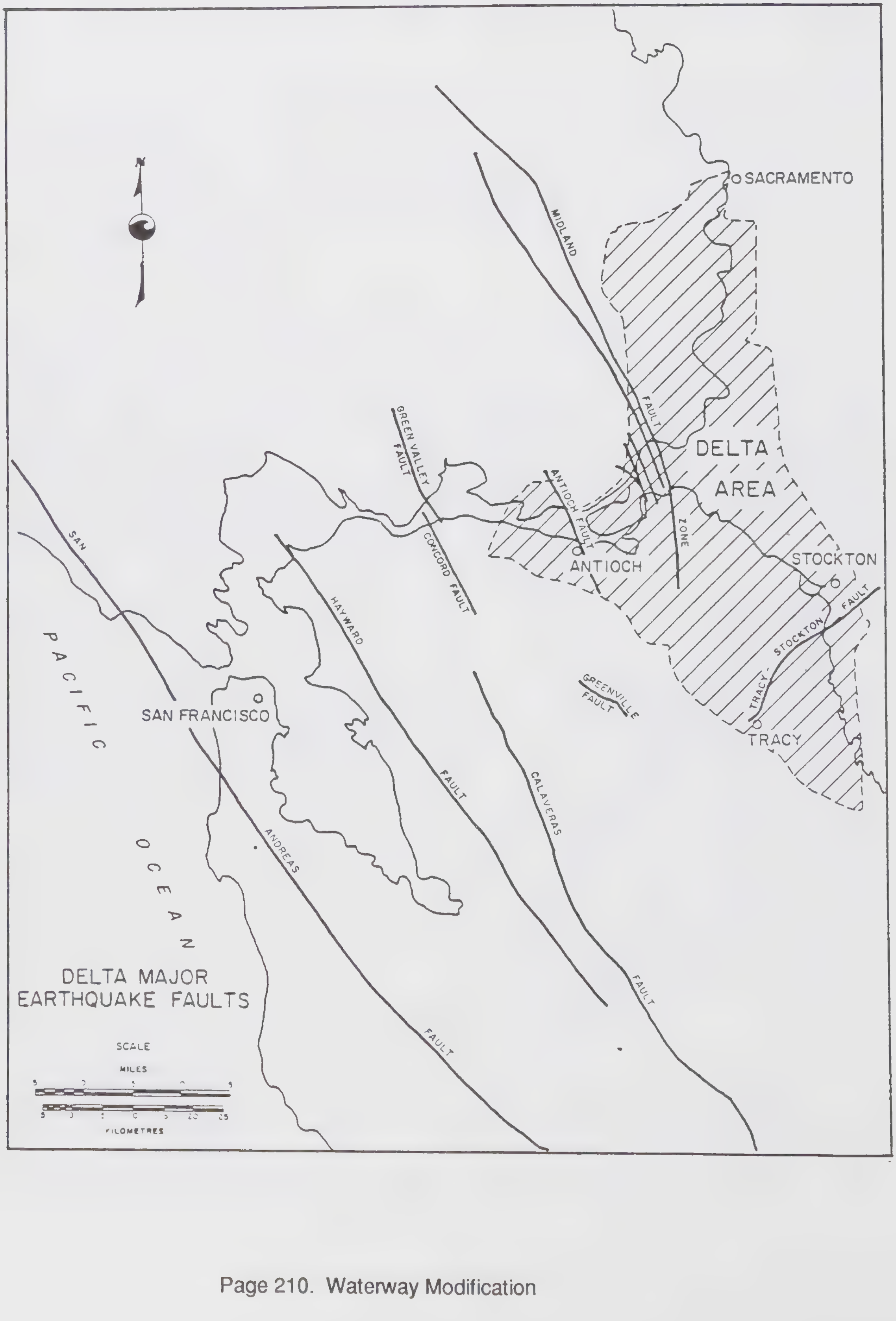


Fig. 42. Major earthquake faults in the region of the San Francisco Estuary. After DWR (1980a).



maintenance. Levees around San Francisco Bay constructed of compacted Bay Mud appear to be more resistant to this type of failure.

The predominant cause of levee failure due to erosion is wave action at high water, although boat wakes contribute to the problem in some locations in the Delta (Limerinos and Smith, 1974). Shoreline levees constructed on the natural marsh plain edge are most at risk, as they are exposed to considerable wind fetch. Within the Delta, the leveed islands protect each other against wave action by limiting the wind fetch (Josselyn and Atwater, 1982). However, where islands have been abandoned (e.g., Frank's Tract), appreciable wave action can be generated, causing erosion problems for the adjacent islands. A marshplain fringe on the outboard side of the levee can appreciably reduce wave energy affecting the levee. Sometimes, this tidal marsh is destroyed by dredging for material to maintain the levee. In other cases, shoreline erosion has eliminated this fringe.

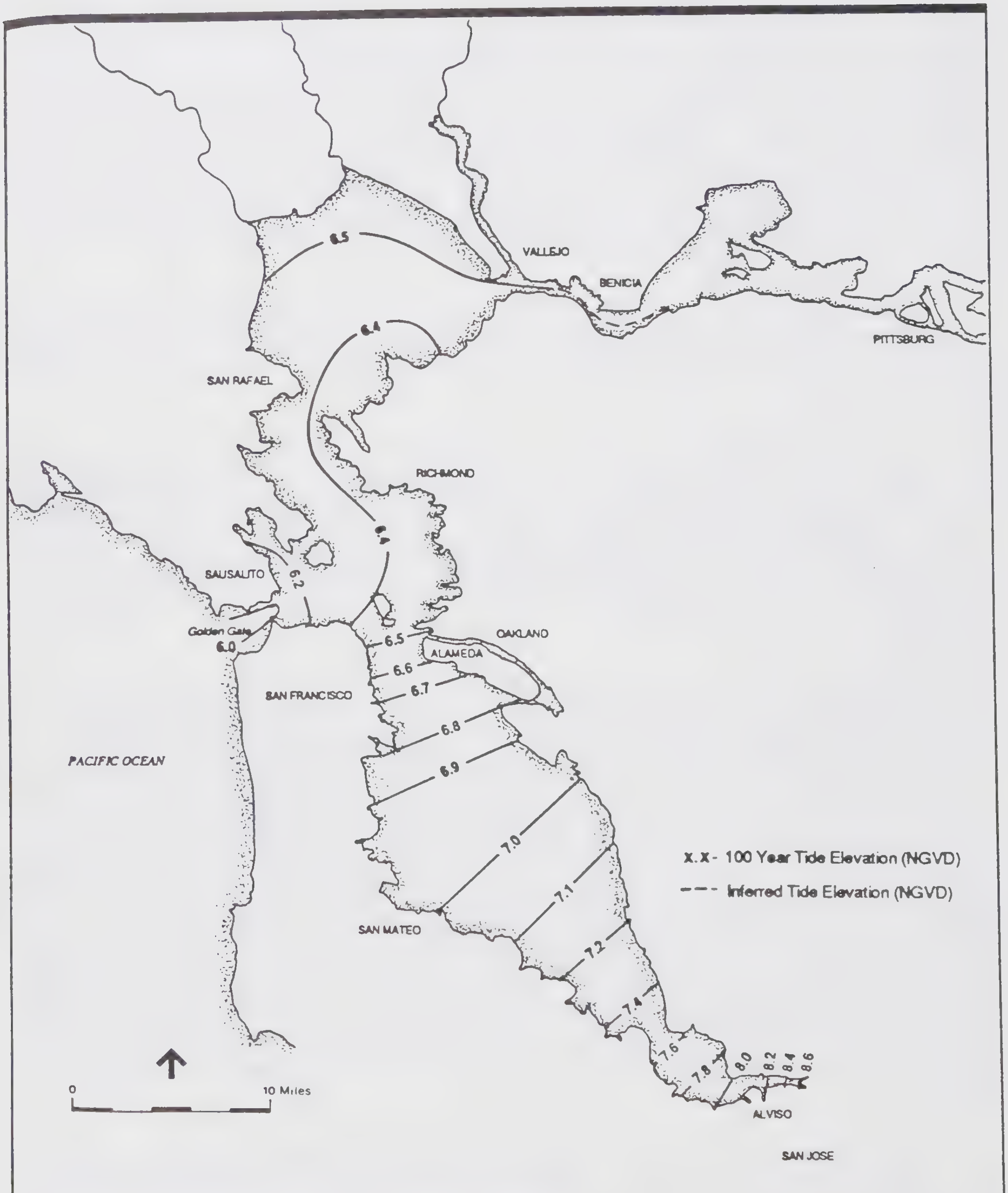
Levees can also fail by overtopping during high water, eroding the back face of the levee. High water at a particular location can be caused by high river discharge, high local runoff levels, high tides and storm surges, wave set-up, seiching, and tsunamis.

The general design standard intended for levee crowns is the "once-in-a-100-yr" water surface elevation due to the combined effect of high tides, river discharge, and local runoff, with an additional freeboard for expected wave run-up. Estimating the 100-yr water surface elevation within the Estuary is complex, as it involves the analysis of the joint probability of a number of different, partially-correlated factors such as atmospheric pressure, precipitation, and perigean tides. So far, no comprehensive analysis has been done.

Estimates of the 100-year high tide have been developed for various stations around the Bay, derived from the historic record of the Presidio tide gage (USCOE, 1984). These elevations provide a minimum 100-year high water level that is used in flood insurance studies (Fig. 43). For those locations affected both by floods and high tides, high-water elevations are determined by a variety of assumptions that typically include analyzing the backwater profile of various-sized floods with various combinations of tidal stage. None of the analyses of high water takes into account possible localized effects such as local storm surges that have been observed at the head of southward-facing Bays such as Richardson Bay. Historic tide and runoff data exist for a number of stations around the Bay that could be analyzed to give more accurate estimates of 100-year high water levels. Wave set-up is analyzed using standard methods that take into account wave fetch and wind speed (BCDC, 1987). Seiching initiated by storm systems or earthquakes is generally not considered to be a factor in elevating water surface elevations. However, no specific analysis has been carried out.

The central part of San Francisco Bay is susceptible to tsunamis generated by earthquakes in the North Pacific (USCOE, 1975c), as occurred in 1964. However, the energy is quickly dissipated as the tsunami moves into the Bay, and only in parts of the

Fig. 43. 100-year Highest Estimated Tide Elevation. After BCDC (1987)



100-Year Highest Estimated Tide (HET) Elevation

SOURCE: U.S. Army Corps of Engineers, 1984

Central Bay do the once-in-100-year tsunami elevations exceed the once-in-100-year high-tide storm surge conditions.

Within the Delta, USCOE (1976f) has systematically analyzed the historic water surface elevations to determine the once-in-100-year high water stage. They then used a tidal hydrodynamic model to project water surface elevations throughout the Delta. These values are currently used as design standards and for flood insurance purposes. Unfortunately, this analysis (carried out in 1976) used the historic record of the period 1945 to 1974. It therefore does not include the record high water stages that occurred in 1983 and 1986. Updating of this analysis could substantially improve the reliability of these estimates.

Even with the existing estimates of 100-year high water levels, many levee crowns are too low, including most of the levees in the Delta. Levees in Suisun Marsh are generally lower than the 100-year high tide elevation (Ramlit, 1983); however, the consequences of overtopping in Suisun Bay are not as severe as elsewhere, as generally they protect managed wetlands. Almost all of the levees surrounding the Estuary require periodic rebuilding because of settlement and compaction of the levee material. This is most severe on the Delta islands, where some peat levees require annual maintenance because they compact very rapidly. In some instances where heavier sand is used to raise a peat levee, the ultimate settlement can be greater than the height the levee is raised.

In urbanized areas around the Estuary where creeks have been channelized, levees extend a considerable distance inland to protect against backwater overtopping during floods coincident with high tides. Many of these flood control projects were designed without fully considering the effects of Estuarine sedimentation in their lower reaches. In order to ensure that the design water surface is not exceeded upstream, continued maintenance dredging of the channel has to be carried out (e.g., Alameda Creek).

C. FAILURE OF INTERNAL DRAINAGE SYSTEMS

Most areas protected against high water levels in the Estuary by levees are susceptible to flooding from local runoff during prolonged high-intensity rainstorms - as occurred in the Bay Area in 1982. Generally, an artificial drainage system of ditches and storm drains collects runoff into a low-lying retention pond or sump. The water is then pumped to the Bay or discharged to the Bay through tide gates at low tide. The difficulties and expense of maintaining this system were often not accounted for when low-lying areas were developed. In some cases this internal drainage system has evolved over time from field ditches to urban storm drains and is not efficiently designed. Frequently, local flooding problems occur where subsidence or low-invert gradients limit the capacity of the drainage system. The most frequent cause of failure is due to pump or control-gate malfunctioning during flood events. This is often due to power failure, and many locations do not have back-up diesel generators for pumps.

Areas that rely on gravity drainage often encounter problems of inadequate flood protection due to leaking tide gates or silted-up outfall channels leading to . All of

these problems are aggravated (and the area inundated increased) where subsidence continues to occur, which happens in most areas developed on former marsh plains.

D. SHORELINE EROSION

It appears that many areas around the perimeter of the Estuary are experiencing a net retreat (BCDC, 1988b). Erosion rates of about 1 m yr^{-1} have been reported in the last 30 years (Josselyn and Callaway, 1988). This shoreline erosion threatens a considerable portion of the remnant tidal marsh plains on the outboard side of levees. In addition, it is threatening the integrity of levees in some areas, requiring costly erosion protection. The major cause is wind-generated waves, although in some locations boat wakes may be a contributing factor (Limerinos and Smith, 1974).

No analysis has been carried out to determine whether erosion is part of a natural cycle due to fluctuating wind patterns or whether it is due to changing sediment dynamics within the Estuary. Erosion of mudflats and shallow subtidal areas in some locations appears to coincide with the reduction in sediment input after passage through the Estuary of the "mud wave" from hydraulic mining. Increases in offshore water depths of even 30 cm can substantially increase wave energy attacking a shoreline at high tide. It is possible that the long-term changes in the sediment budget of the Estuary are affecting deposition in shallow areas and, consequently, affecting the position of the shoreline.

Another factor that could be important is relative rate of sea-level rise. This has shown some increase over the last tidal epoch to about 20 cm per century (BCDC, 1987). The relative rise can be greater in areas experiencing continued subsidence. In a sediment-rich system such as San Francisco Bay, this rate of rise can be compensated in sheltered areas and on marsh plains by sedimentation. However, on the Bayfront shoreline increased wave energy would limit sedimentation leading to increased shoreline erosion.

No analysis has been carried out to determine overall changes in bathymetry or morphology of the Estuary. Information from the most recent hydrographic survey of the 1970s and 1980s is available but has not been analyzed.

BCDC has recently enacted new regulations to encourage the use of environmentally sensitive and effective erosion control techniques for shoreline areas where structural measures are necessary.

V. FUTURE TRENDS

A. COASTAL FLOODING

There is a significant risk of major flood damages occurring in the next 50 yr, due to the poor condition of levees and the existing probabilities of high water, . The problem is acute in the Delta, where many of the Delta islands have an estimated risk of inundation of once in less than 20 yr. Here the problem is compounded by increasing difficulty in finding accessible material to reinforce levees as they subside. Borrow ditches, the ditches adjacent to the levee used to supply sediment to build the levee, are now 4 to 5 times larger than the levees themselves, and as sediment inflow to the Delta is declining, maintenance will become more expensive (Thompson, 1982).

Future flood damage will be greatly influenced by actions taken to improve flood protection, changes in land use and agricultural methods in flood-prone areas, and changes in the frequency and magnitude of high-water levels. Increased levee maintenance in the Delta provided by SB 34 will likely reduce the frequency of inundation for smaller floods but would not protect the islands against major floods such as the 100-year high water stages. DWR is also in the process of developing water management programs for the Delta that might lead to significant upgrading of levees around Sherman Island and the North Delta (DWR 1988a, b).

The San Francisco District, USCOE, continues to analyze the feasibility of a bayfront levee to protect urban areas as part of its San Francisco Bay Shoreline Study and Marin County Shoreline Study. Elsewhere, individual flood control districts or public works agencies upgrade segments of flood control levees as funds become available, usually in connection with new urban development.

There is strong pressure to urbanize flood-prone low-lying land adjacent to the Estuary. When this happens, the risk of increased flood damage increases. In some instances, the existence of seasonal wetlands in these areas has prevented development. Elsewhere, agricultural land is being urbanized. Although in many instances building pads are above the 100-year flood level, long-term flood protection that recognizes subsidence and future flood levels, is seldom provided. For example, low-lying areas of East Contra Costa County are under development pressure at present. Some of this area is protected by inadequate, non-engineered agricultural levees.

An increase in the frequency and magnitude of high water levels can be caused by subsidence, rise in sea level, and increase in magnitude of flood flows. Subsidence will continue to occur in areas developed on former tidal marshes (for example, parts of the Santa Venetia subdivision in Marin County have experienced a fairly uniform decline in elevation of about 2.5 cm yr^{-1} since the 1960s). Levees also subside as material compacts. Throughout the Estuary, tectonic subsidence rates are generally low, less than 0.7 mm (0.3 in) yr^{-1} (Atwater *et al.*, 1977). Unfortunately, no first-order survey is in place to monitor long-term subsidence from all effects. It appears that the South Bay has the greatest subsidence rates (BCDC, 1987). Regional subsidence

rates in the Delta are also poorly defined due to lack of accurate surveys. Localized subsidence rates due to loss of peat soils have been well-documented and are likely to continue at rates of about 5 cm yr^{-1}. Continued lowering of the land surface in the western Delta islands will increase the risk of levee failure due to piping, slumping, and earthquake failure in the future. This will be true even if the levees are reconstructed to current USCOE design standards.

Sea level will continue to rise and will continue to aggravate flood hazards. The historic rise in sea level has been about 15 cm per century, increasing to 20 cm per century over the last 19-yr tidal epoch. At present, many agencies do not routinely incorporate expected subsidence rates or sea-level rise rates over the lifetime of a project in establishing flood protection criteria. In 1989, BCDC enacted regulations for projects within its jurisdiction that did include both these criteria. However, levees and flood control systems built prior to 1989, or those outside BCDC jurisdiction, may prove to be inadequate in the future.

FEMA criteria for designating its 100-year flood hazard zones are restricted to considering only present flood hazards and not likely future hazards. The design criteria for flood protection used by all agencies make the assumption that there will be no changes in climate. Scientific opinion is now nearly unanimous that regional climates will change due to global warming from the "greenhouse effect." Although predictions of the magnitude of changes vary considerably, there is a consensus that the rate of sea-level rise will accelerate and that mid-latitude regions such as California will become warmer.

The range of predictions of likely rate of sea-level rise is shown in Fig. 44. For planning studies, EPA uses a mid- range estimate of global sea-level rise of 1 meter over the next 100 yr. Because the projected increases in sea level are exponential, this would amount to about 0.3 m over the next 50 yr. Such an increase in sea level would have a major effect on San Francisco Bay, not only increasing flood hazards but affecting natural resources and water resources management (Williams, 1986). The increase in sea level would be experienced as an increase in frequency of extreme storm-surge events such as those that occurred in 1983.

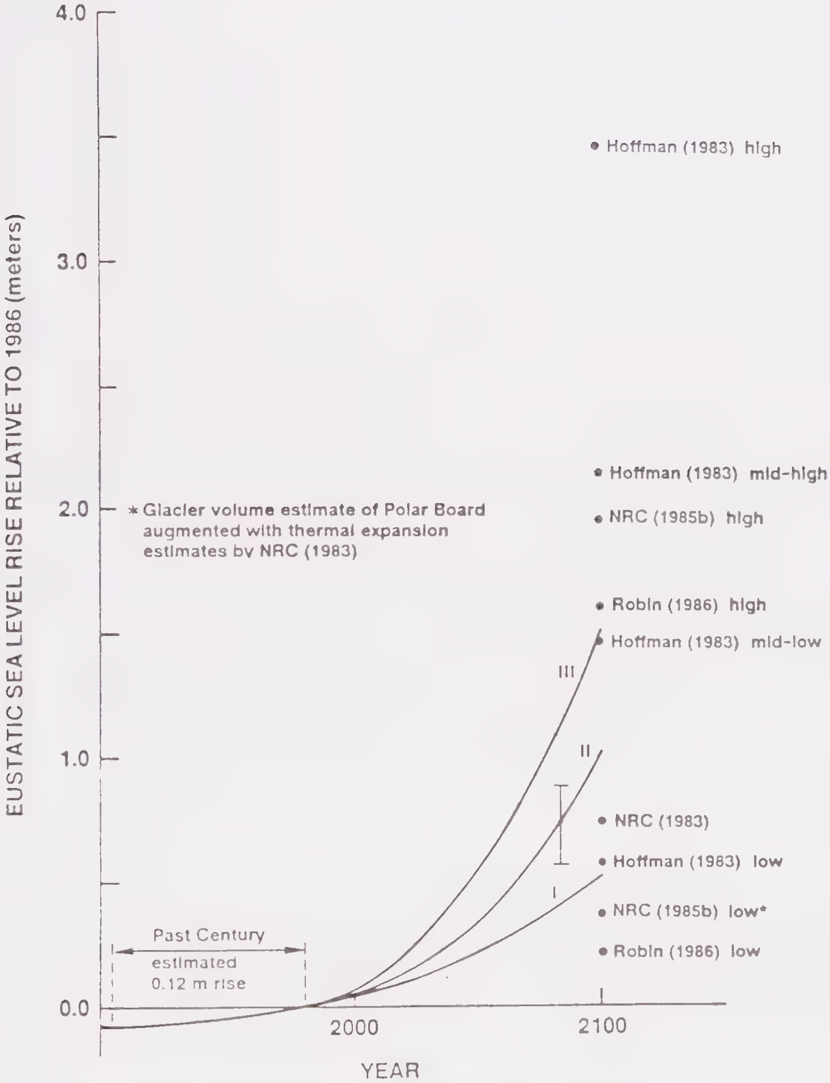
Even without levee failures, accelerated sea-level rise would greatly alter the morphology, hydrodynamics, and salinity of the Estuary, requiring substantial changes in water management in the Delta (Williams, 1988). With the failure of Delta island levees, these effects would be more pronounced.

Global warming would also directly affect the hydrology of the Central Valley. Winter precipitation that now falls as snow at higher altitudes would become rain, increasing winter rain floods at the Sacramento River (Gleick, 1988). This would cause more frequent higher water stages, particularly in the North Delta.

B. SHORELINE EROSION

Future trends in shoreline erosion depend on measures taken to protect against shoreline erosion, future increases in sea level, and future trends in the overall sediment budget of the San Francisco Estuary. Because levees were often

Fig. 44. Eustatic sea-level rise scenarios. After National Research Council (1987).



constructed on the outer edge of the historic marshplain, the buffer areas between the levee and retreating marsh edge are narrow or non- existent in many instances. Levee erosion is usually dealt with on an *ad hoc* basis by hardening the levee slope with riprap or rubble. In only a few instances are wetlands protected in this manner.

The effect of rising sea level on the marshplain is determined by the rate of sedimentation; effects of sea level rise will be less if sedimentation elevates the marshplain at a similar rate. This, in turn, depends on the availability of sediment brought in by the tide, which, in turn, is dependent on the overall sediment budget of the Estuary. With existing sediment inputs to the Estuary, rough estimates have been made of the effect of accelerated sea-level rise on marsh erosion (Josselyn and Callaway, 1988). Rates of erosion accelerate rapidly for rates of sea-level rise exceeding 1 meter per century. Climatic change might also alter the frequency and intensity of wave action within the Bay. No projections have been made whether these changes would increase or decrease erosion.

Rising sea level and/or geomorphic changes due to permanent inundation of Delta islands might reduce sediment delivery to the Estuary; however, this might be counterbalanced by increased flood flows delivering more sediment. Unfortunately, there has been no recent attempt to quantify crucial components of the overall sediment budget of the Estuary that affect shoreline erosion. Sediment delivery is greatly influenced by reservoir management. Predicted reduction in sediment delivery (Krone, 1979) would affect sediment storage within the Estuary through erosion of mudflats and shallow subtidal areas. Such effects would allow for significantly greater wave action against the shoreline, and would increase erosion rates. Long-term changes in San Francisco Bay morphology have not been analyzed since the study of Smith (1963).

VI. GAPS IN KNOWLEDGE, MANAGEMENT OPTIONS, AND RECOMMENDED RESEARCH

The review of status and trends waterway modification in the San Francisco Estuary reveals several important topics about which little is known. This Section briefly summarizes these areas of inadequate technical knowledge, or "data gaps", providing examples of management questions raised by these gaps in understanding. This section also includes recommendations for research and monitoring to provide information on areas that have important implications for management of waterway modification in the Estuary.

A. GAPS IN KNOWLEDGE

(i) *Coastal flooding*. What are the most recent 100-year high water level estimates for the Estuary? How can they be adjusted to account for the probabilities of flood flows and storm surges? What are the consequences of Delta Island failure on San Francisco Bay morphology, hydrodynamics and salinity? What is the present condition of the perimeter levees surrounding the Bay and the Delta?

(ii) *Shoreline erosion*. What are the long-term trends in shoreline erosion? What are the causative factors? Can a current sediment budget be produced for the Estuary? How can sediment transport data be analyzed to update the sediment budget for the Estuary?

(iii) *The extent (both historical and current) of stream channelization for flood control and stormwater management purposes*. How much material has been dredged for this purpose? Over what distances have streams been modified? What effects do these activities have upon local biota, including fisheries and riparian vegetation? What effects do these activities have upon local sedimentation rates, and other aspects of habitat viability? Is channelization a significant factor in the loss of fish and other wildlife habitats?

B. MANAGEMENT OPTIONS

The San Francisco Estuary Project of the U.S. EPA, in managing the production of this report, decided that the description of management options would be provided by the *Sub-Committee on Dredging and Waterway Modification*. The Sub-Committee is drafting management options for waterway modification, and these will be issued at a later date.

C. RECOMMENDED RESEARCH

It is recommended that estimates of 100-year high water levels around the Estuary be updated and revised to systematically account for the joint probability of flood flows and storm surges. Consistent flood protection design standards should be developed for different land uses around the Estuary, and analyses performed to allow future planning for coastal flood protection to account for projections of sea-level rise.

The consequences of failure of the Delta islands upon the morphology, hydrodynamics, and salinity distribution of the Estuary need to be analyzed to determine management strategies for the Delta. In addition, it is recommended that a comprehensive survey of the condition and elevation of all perimeter levees surrounding the Estuary be undertaken; there is a also a need for a detailed topographic survey of low-lying areas around the Estuary, to determine areas of risk under future hazard scenarios.

Existing bathymetric surveys and sediment transport data should be analyzed to update the sediment budget for the Estuary. Periodic bathymetric surveys need to be made of mudflat and shallow inter-tidal areas to monitor long-term changes in Estuary morphology that might affect shoreline erosion. There is also a need for a coordinated, long-term plan for the future of the Delta.

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APPENDIX 1

I. HYDRAULIC MINING

Hydraulic mining, which began in 1853, employed pressurized water to extract gold from the hills and mountains of the Sierra Nevada Range. By the early 1880s, five hundred mines, representing an aggregate capital investment of $100 million were in operation. Extensive water systems were built, which at the peak of the mining used approximately 740 million m^3 yr^{-1} (Hagwood, 1976).

Gilbert (1917) estimated that, between 1849 and 1914, 1.5 billion yd^3 of debris flowed out of the Sierras toward the sea (Table A1). Much of this material eventually washed into the major rivers of the Central Valley, impeding navigation, and causing devastating floods. Gilbert estimated the volume of material that settled out in the San Francisco Bay system to be 200 million yd^3 in Suisun Bay, 50 million yd^3 in Carquinez Strait, 570 million yd^3 in San Pablo Bay, and 326 million yd^3 in San Francisco Bay (a total of over 1 billion yd^3). This mass of sediment resulted in deposits of sediment 1 m deep in Suisun Bay, 0.8 m in San Pablo Bay, and 0.2 m in San Francisco Bay.

II. HISTORICAL MAINTENANCE DREDGING BY THE SAN FRANCISCO DISTRICT

The San Francisco District maintains records of their maintenance dredging activities in the Bay (USCOE, 1989a). For some projects, annual volumes dredged during the last 50 years are available, providing a useful basis for discussion of long-term trends in maintenance dredging. Table A2 is a summary of these data. Only data from 1975-1985 were discussed in the main report because data from each project were not uniformly available prior to 1975. For additional details on the history, location, and dimensions of these projects refer to USCOE (1975b) and USCOE (1985).

A. San Francisco Harbor

The San Francisco Harbor Project was the first Congressionally-authorized dredging project in San Francisco Bay, and was initially dredged in 1868.

The San Francisco Harbor Project called for the creation of an approach area to Islais Creek, a channel to the San Francisco Airport, and a Main Ship Channel outside the Golden Gate. The Islais Creek Entrance Channel, on the eastern San Francisco waterfront, was authorized by the *River and Harbor Act* of 1927, and was first dredged to its authorized dimensions in 1939. From 1955 to 1977, when maintenance dredging last occurred in Islais Creek, 1.0 million yd^3 of material was removed by hopper dredge and disposed at the Alcatraz site.

Table A1. Estimated volume of sediment washed into Sierra Nevada rivers from mining operatons in the late 1800s (after Gilbert, 1917).

LOCALITY	VOLUME (million yd^3)
Upper Feather River	100
Yuba River	685
Bear River	255
American River	255
Mokelumne-Tuolumne area	230
Butte Creek-Cherokee Canal	30
Total	**1,555**

Table A2. Summary of maintenance dredging by the USCOE in San Francisco Bay from the 1930s to the present. Data from USCOE (1989a).

PROJECT	LOCATION	PERIOD OF RECORD	TOTAL DREDGED (MILLION YD3)	DISPOSAL SITE
San Francisco Harbor	Islais Creek Channel	1955-1977	1.0	Alcatraz
	San Francisco Airport	1955-1962	0.7	Land
San Pablo Bay	Mare Island Strait	1931-1988	96.0	Carquinez
	Pinole Shoal	1936-1987	20.0	San Pablo Bay
Richmond Harbor	Inner Harbor	1954-1987	14.0	Alcatraz
	Outer Harbor	1956-1987	3.8	Alcatraz
Oakland Harbor	Inner Harbor	1954-1988	8.8	Alcatraz
	Outer Harbor	1954-1988	10.9	Alcatraz
San Rafael Creek	Channel Across Flats	1947-1986	0.9	Alcatraz
	Inner Channel	1931-1987	1.6	Land
San Leandro Marina		1978-1984	0.5	Land
Redwood City Harbor	5 Foot Channel	1950-1960	0.2	Land
	Entrance Channel	1954-1984	3.3	Alcatraz
Napa River		1962-1981	1.2	Land
Suisun Bay Channel		1977-1987	1.2	Suisun Bay
Suisun Slough Cha nnel	Entrance and New York Sl	1960-1982	0.2	Suisun Bay
	Suisun Slough	1982	0.1	Land
Petaluma River	Channel Across Flats	1941-1987	2.8	San Pablo Bay
	River Channel	1937-1983	3.0	Land

Maintenance dredging at the San Francisco Airport has occurred twice, in 1955 and 1962. A total of 700,000 million yd^3 of material was removed from the San Francisco Airport Channel and disposed on land .

B. San Pablo Bay and Mare Island Strait

Initial navigational improvements at Mare Island Strait were conducted by the Department of the Navy in 1882. The first Federal project at Mare Island was authorized by the *River and Harbor Act* of 1902. The existing project, the Mare Island Ship Channel, was authorized by the *River and Harbor Act* of 1927 and provides for dredging and maintenance of a channel across the Pinole Shoal in San Pablo Bay. The channel ends in a turning basin between Vallejo and Mare Island.

The Mare Island Strait project accounted for most of the maintenance dredging performed by the San Francisco District in the last 60 years. Since 1931, 96 million yd^3 of material (averaging approximately 1.6 million yd^3 annually) have been removed by hopper dredge, and disposed of at the Carquinez Strait disposal site.

Dredging of the Pinole Shoal, which leads to the entrance of the Mare Island Ship Channel, was first authorized under the *River and Harbor Act* of 1911. Subsequent authorizations deepened and widened the channel; it was first dredged to its present dimensions in 1929. Since 1936, 20 million yd^3 of material have been removed from the Pinole Shoal by hopper dredge (average of 380,000 yd^3 annually) and disposed at the San Pablo Bay disposal site.

C. Richmond Harbor

This project was initially adopted by the *River and Harbor Act* of 1917, and has been modified by a series of Acts since that time. The Richmond Harbor Project consists of two sub-projects, the Inner and Outer Harbors. From 1954-1987, 14 million yd^3 of sediment was dredged from the Inner Harbor. From 1956-1987, 3.8 million yd^3 was removed from the Outer Harbor. Although USCOE (1989a) lists all of this material from the Inner and Outer Harbors as having been disposed of at Alcatraz, USCOE (1975b) stated that from 1951 through 1971, material was disposed at an area to the east of Angel Island. Prior to that time, other aquatic disposal sites closer to the project were employed. The disposal site at Alcatraz was used after 1972 (USCOE, 1975b).

D. Oakland Harbor

Oakland Harbor has been dredged since the *River and Harbor Act* of June 23, 1874 called for the construction of two jetties (USCOE, 1975b). Subsequent Acts have modified and enlarged the initial project. This project can be divided into two sub-projects; the Inner and Outer Harbors. The total length of the Inner Harbor Channel is 13.6 km (USCOE, 1988a). From 1954-1988, 8.8 million yd^3 of sediment were dredged from this Channel. This corresponds to an annual rate of maintenance dredging of approximately 250,000 yd^3.

Dredging of the Oakland Outer Harbor was first authorized by the *River and Harbor Act* of 1927. This project consists of an entrance channel 5.4 km in length,

commencing in the deep water of Central San Francisco Bay, cutting across a shoal southeast of Yerba Buena Island, and terminating at the head of Outer Harbor. Since 1954, 10.9 million yd^3 of material have been dredged from this site. This corresponds to an annual rate of maintenance dredging of approximately 310,000 yd^3.

Although USCOE (1989a) lists all dredged material since the mid-1950s from Oakland Harbor as having been removed by hopper dredge and disposed at Alcatraz, USCOE (1975b) states that sediments excavated from the Inner and Outer Harbors were removed by hydraulic pipeline, clamshell, and hopper dredge. The sediment removed by clamshell and hopper dredge prior to 1970 was disposed either near Yerba Buena Island, or at a location somewhere between Yerba Buena Island and San Francisco. Materials removed by hydraulic pipeline were probably disposed of on land adjacent to the channel (USCOE, 1975b). Dredged material removed from Oakland Harbor after 1970 was disposed at Alcatraz. An unknown quantity of material dredged for improvements in 1975 was disposed of at the 100-fathom (183 m) site near the Gulf of the Farallones (USCOE, 1975b).

E. San Rafael Creek

Dredging of the flats in San Francisco Bay, which extend to the mouth of the San Rafael Creek, was provided for by the *River and Harbor Act* of 1919. This channel was completed in 1928. Since 1931, 2.5 million yd^3 of dredged material from maintenance operations have been excavated by hydraulic pipeline and clamshell dredge, and disposed of both at Alcatraz and at land sites along the creek. This rate of dredging averaged less than 50,000 yd^3 annually.

F. San Leandro Marina

During the late 1950s and the 1960s, the USCOE studied the feasibility of Federal participation in the development of harbors for shallow-draft vessels. On September 8, 1964, the City of San Leandro submitted a resolution requesting Federal maintenance of the locally-built access channels to the San Leandro Marina. In 1970 House Document 91-428 was adopted, providing for the maintenance of the main access channel to the San Leandro Marina. A series of smaller channels that lead to a turning basin and an auxiliary channel were later authorized. Between 1978 and 1984, the San Francisco District transported 500,000 yd^3 (averaging 70,000 yd^3 annually) by pipeline to a land disposal site.

G. Redwood City Harbor

Dredging activities at Redwood City Harbor were first authorized by the *River and Harbor Act* of 1884. The existing project was authorized in 1910 and provided for the dredging of a channel across San Bruno Shoal in San Francisco Bay, a channel near the confluence of West Point Slough and Redwood Creek, and for two turning basins. This site was dredged on 14 separate occasions between 1950 and 1984. A total of 3.5 million yd^3 of maintenance material was dredged, equivalent to an average annual rate of 100,000 yd^3.

A discrepancy exists between the records of USCOE (1989a) and USCOE (1975b) regarding the disposal site employed for these materials and the quantities dredged. The maintenance dredging requirement at this site was estimated to be 325,000 $yd^3\ yr^{-1}$ by USCOE (1975b), in contrast to the estimate presented above. Furthermore, USCOE (1989a) shows that dredged material from the 1950s to the present was disposed at Alcatraz; USCOE (1975b), however, states that prior to the late 1970s, sediment excavated from the Redwood City Harbor project was deposited at various land disposal sites surrounding the project, and in the South Bay.

H. Napa River

Dredging activities on the Napa River were initially authorized by the *River and Harbor Act* of 1888. The existing project was authorized by the Acts of 1935 and 1946, which provided for a channel from the Mare Island Strait Causeway to Asylum Slough, a turning basin, and additional widenings, realignments, dikes, and revetments as required. According to USCOE records, maintenance dredging over the last 30 years has been limited to two episodes in 1962 and 1981, when a total of 1.2 million yd^3 of material was transported by pipeline to a land disposal site.

I. Suisun Bay Channel

Originally authorized by the *River and Harbor Act* of 1919, and later modified, this project provided for the construction of a channel from Avon to New York Slough, (a distance of 21 km), plus maintenance dredging from the main channel to Point Edith, and to the main channel again at Port Chicago. Until 1974, when maintenance dredging responsibilities were turned over to the San Francisco District of the USCOE, channel creation and maintenance dredging in the Suisun Bay Channel was performed by the Sacramento District of the USCOE (V. Crisson, personal communication). The volume of material dredged from Suisun Bay Channel between 1919 and 1976 is not known, although USCOE (1975b) estimated the maintainence dredging requirement to be 220,000 yd^3 annually. Material was removed from the channel by hydraulic pipeline, hopper, and clamshell dredge. The authorized aquatic disposal site in Suisun Bay used to receive the dredged material was located north of and parallel to the channel (USCOE, 1975b). Dredging activities conducted recently have been better documented than those in the past. From 1977 through 1987, 1.2 million yd^3 of sediment have been excavated by hopper dredge and disposed near the Suisun Bay channel (USCOE, 1989a). This is an average of 109,000 yd^3 annually.

J. Suisun Slough Channel

Authorization for dredging of the Suisun Slough Channel was initially provided by the *River and Harbor Act* of 1910. Dredging of Suisun Channel by hydraulic pipeline began in 1912, and the sediment was initially placed on land, although a nearby aquatic disposal site was later employed (USCOE, 1975b). The land disposal sites employed for disposal of dredged material from the Suisun Slough Channel project are not well-defined. From 1960-1982, the San Francisco District dredged approximately 300,000 yd^3 of sediment from the Suisun Slough area, and disposed of the material on land and in Suisun Bay.

K. Petaluma River

Initial authorization for dredging on the Petaluma River was granted by the *River and Harbor Act* of 1880. The existing project was adopted by the *River and Harbor Act* of 1930, and was completed in 1933. This project consists of a channel across the flats in San Pablo Bay to the mouth of the river and to a turning basin in Petaluma. From 1937 through 1983, 3.0 millon yd^3 of dredged material were excavated from the Petaluma River Channel and disposed on land. Dredging of the outer channel from 1941-1987 contributed an additional 2.8 million yd^3 that was disposed at the San Pablo Bay site.

III. DREDGING BY THE U.S. NAVY

The U.S. Navy maintains records of their dredging activities in the Bay (US Navy, 1989). These records provide the best historical information available regarding volumes of sediment dredged at Naval facilities. For some facilities, data from the 1940s to the present are available. Table A3 is a summary of these data. Unless stated otherwise, data presented below are from US Navy (1989). It should be noted that the Navy records do not distinguish between maintenance and new work dredging. Data for each naval facility are discussed below. Only data from 1975-1985 were discussed in the main report because data from each project were not uniformly available prior to 1975.

A. Alameda Naval Air Station

The Alameda Naval Air Station (NAS), located just south of the entrance to Oakland Harbor, has been dredged since its construction in 1937. A total of 20 million yd^3 of sediments was dredged from this site between 1959 and 1988. This corresponds to an average dredging rate of approximately 670,000 yd^3 annually. Hopper, clamshell, and hydraulic pipeline dredging methods were employed at this site. Since 1975, this material has been disposed at Alcatraz, with minor amounts disposed on land. Prior to 1975, disposal also took place at aquatic sites near the Air Station, and at the 100 fathom site near the Gulf of the Farallones (USCOE, 1975b).

B. Naval Supply Center, Oakland

According to Navy records, dredging activities began at this site in 1940, when over 4 million yd^3 of material were removed by hydraulic pipeline and used as landfill to construct the Naval Supply Center (USCOE, 1975b). Approximately 13 million yd^3 of sediments were dredged at this site between 1940 and 1988 (US Navy, 1989). This corresponds to a long-term average rate of dredging of 280,000 yd^3 . Between 1940 and 1970 dredged sediment was disposed near the southwest side of Yerba Buena Island. By 1975, it was agreed that any disposal of dredged material would take place at Alcatraz unless it was heavily contaminated, in which case it would be transported to the 100-fathom (182 m) disposal site in the Gulf of the Farallones (USCOE, 1975b).

Table A3. Summary of maintenance dredging by the U. S. Navy in San Francisco Bay from the 1940s to the present. Data from US Navy (1989).

FACILITY	LOCATION	PERIOD OF RECORD	TOTAL DREDGED (MILLION YD3)	
Alameda Naval Air Station	Oakland Harbor	1959-1988	20.0	Alcatraz, nearby aquatic sites, land
Naval Supply Center, Oakland	Oakland Harbor	1940-1988	13.0	Alcatraz, nearby aquatic sites
Point Molate Naval Fuel Depot	Richmond	1943-1988	6.0	Alcatraz, other unknown locations
Mare Island Naval Shipyard	Mare Island	1980-1988	5.2	Land
Naval Weapons Station, Concord	Concord	1943-1988	1.9	Carquinez, nearby aquatic sites, land
Moffett Field Naval Air Station		1956-1985	1.1	Alcatraz, land
Naval Station Treasure Island	Treasure Island	1953-1985	1.0	Alcatraz, land
Hunters Point Naval Shipyard	San Francisco	1972-1986	0.7	Ocean, Alcatraz

C. Point Molate

The Point Molate Naval Fuel Depot is located just north of the Richmond-San Rafael bridge on the Richmond shoreline. Dredging at this facility began in 1943, with construction of the pier and berthing area. A total of 6 million yd^3 of material was dredged at this site between 1943 and 1988, corresponding to an annual average of 132,000 yd^3. The annual average rate of dredging at this site over the last decade has been 74,000 yd^3. The disposal site for material dredged prior to 1975 is not known (USCOE, 1975b). By the mid-1970s, dredged material from Point Molate was being placed at the Alcatraz disposal site.

D. Mare Island

Mare Island Strait has been an important waterway since 1854, when the Bureau of Yards and Docks, U.S. Navy, chose a site on Mare Island as a shipyard. In addition to the dredging performed by the San Francisco District of the USCOE, the Navy has dredged in the vicinity of Mare Island since the late 1880s. Between 1980 and 1988, 5.1 million yd^3 of material have been dredged over this period, averaging 570,000 yd^3 annually. This dredging is performed with a hydraulic cutter suction dredge, which is owned and operated by the Navy and operates 16 hours daily, 5 days a week. The dredge is connected to any of four permanent pipelines which run across Mare Island to seven diked lowland areas on the western side of the Island (USCOE, 1975b).

E. Naval Weapons Station - Concord

Located on the south side of Suisun Bay, the area surrounding this ammunition depot and supply center has been dredged since the facility was constructed in the early 1940s. Between 1943 and 1988, a total of 1.9 million yd^3 of material was dredged at this site. Prior to 1975, dredged material was disposed on land at the Station, or in nearby waters. Due to increasing agency opposition to these disposal practices, and also to sediment test results which revealed elevated levels of heavy metals, sediments dredged in 1975 were disposed of at the Carquinez Strait site (USCOE, 1975b).

F. Moffett Field Naval Air Station

Data from the U.S. Navy (1989) show that 1.2 million yd^3 of sediments were dredged at this site between 1956 and 1985. This corresponds to an annual average dredging rate of approximately 40,000 yd^3. In 1985, 12,500 yd^3 of dredged material was diposed at an upland site on lands owned by the Leslie Salt company.

G. Treasure Island

Between 1953 and 1985, approximately 1 million yd^3 of sediment were dredged at this site, corresponding to an annual average of 31,000 yd^3. The annual average rate of dredging over the last decade is 49,200 yd^3 (U.S. Navy, 1989). In 1985, 35,000 yd^3 of dredged material was disposed of at an upland site.

H. Hunters Point Naval Shipyard

A total of 730,000 yd^3 of material was dredged at this site from 1972-1986. Some 300,000 yd^3 of this was dredged during 1972 and 1973, and disposed at an ocean site (U.S. Navy, 1989). The remainder (430,000 yd^3 over 14 years, corresponding to an annual average of almost 31,000 yd^3) has been disposed at the Alcatraz site.

I. Stockton Naval Communications Station

This site was last dredged about 10 years ago, and occasional dredging activities occurred in the early 1970s as well. No dredged volumes were recorded, and all sediments were disposed of at an upland site.

APPENDIX 2

DREDGING EQUIPMENT

This Appendix briefly describes the types of dredging equipment referred to in this report. The following information is derived from Appendix B of USCOE (1988a).

There are two major classifications for dredges; hydraulic and mechanical. A mechanical dredge excavates sediments directly, whereas a hydraulic dredge removes sediments that are mixed with water in a slurry. In San Francisco Bay, mechanical dredging is normally accomplished using a clamshell dredge, while hydraulic dredging is carried out using a self-propelled hopper dredge or a hydraulic cutterhead dredge.

Most dredging in the Estuary is undertaken using a self-propelled hopper dredge. This type of dredge pumps sediments and water up through pipes into hoppers on the vessel, which gradually fill with the slurry. As the sediments settle in the hopper, more slurry is pumped in to displace water, thereby increasing the quantity of sediment in a given load. The dredge then transports the material to a disposal site, and discharges the load through the bottom of the vessel. Hopper dredges are capable of operating in rough, open waters.

Clamshell dredges utilize a large bucket, which is lowered into the sediments from a boom; sediments excavated by the bucket are subsequently deposited in a barge. The barge (or scow) is towed to the disposal site, and releases the dredged material through doors in the bottom of the vessel. Clamshell dredges are well suited for work in shallow waters, and in confined areas near shoreline structures such as piers. Dredging using clamshell equipment is relatively slow compared to hydraulic methods.

A smaller amount of dredging in the Estuary is carried out using hydraulic cutterhead dredges. These dredges utilize a rotating cutter device that is attached to a suction pipe. Sediments loosened by the cutterhead are transported through the pipe in a slurry (1 part sediment and 4 parts water) and deposited either on land, or to a barge for aquatic disposal. The U.S. Navy uses this type of dredge in its operations at Mare Island.

APPENDIX 3

COMMENTS SUBMITTED ON THE SECOND DRAFT

ENVIRONMENTAL ORGANIZATIONS

Citizens for a Better Environment -- Alan Ramo
Marin Audubon Society -- Barbara Salzman

GOVERNMENT AGENCIES

Contra Costa Water District -- Greg Gartrell
Sacramento County Department of Public Works -- Doug Fraleigh

California Central Valley RWQCB -- Jerry Bruns
California Department of Fish and Game -- Don Lollock
California Department of Water Resources -- Randy Brown

Army Corps of Engineers -- Bob Engler
Department of the Navy -- Lee Michlin
Environmental Protection Agency -- Brian Melzian
National Marine Fisheries Service -- Pat Rutten
United States Geological Survey -- Fred Nichols

USER GROUPS

Pacific Interclub Yachting Association/
Recreational Boaters of California -- Leonard Long

INDIVIDUALS

Arliss Ungar

TECHNICAL EDITOR

Joyce Nuttall

CITIZENS FOR A BETTER ENVIRONMENT

October 24, 1989

Mike Monroe
Technical Program Manager
San Francisco Estuary Project
P.O. Box 2050
Oakland, CA 94604-2050

Re: STR--Dredging and Waterway Modification

Dear Mike:

I apologize for the lateness of this comment, but I know you will understand in light of the earthquake and its aftermath.

I have reviewed the above-described STR and I am very pleased with the results. My impression is that AHI put forth a major effort to respond to our concerns as a committee and in good faith strove to correct the deficiencies in the initial draft. The writing and discussion of the issues is quite scholarly and a fair presentation is generally given to the different points of view on this issue.

There are within the text only a few passages where a different balance might have been more helpful in presenting the data. The discussion of bioassays strikes me as being weighted towards the position that these are not very helpful in predicting environmental effects. I felt the discussion particularly of the Navy's testing results for the Missouri bioassays should have been a bit more forthcoming on the suggestion of toxicity in that testing. Compare the STR discussion with the following passages from Dr. Robert Spies' letters published in the Navy's FEIS:

> Ranking of the stations according to the combined results of the bioassays indicated clearly that the Hunters Point stations were more toxic than the Alameda or Treasure Island stations. (Navy's Final Environmental Impact Statement, Vol. I, Technical Appendices. Appendix B, Part 3. "Relationships Between Bioassays, Contaminant Concentrations in Sediments and Bioavailability of Contaminants from San Francisco Bay Sediments", Robert B. Spies. May 15, 1987, p. 1.
>
> It should be further be realized that relationships established on the basis of correlation do not constitute proof of cause. For example, it is possible that one or more chemicals highly toxic to fish and not measured in these samples is responsible for the mortality of sandabs from HP-3ib and HP-4ib. <u>To the extent that this is possible, our conclusion is tentative that copper, zinc, cadmium, and hydrocarbons and possibly other metals found elevated (or more bioavailable) in Hunters Point sediments are toxic</u>. (Emphasis added). Id., p. 39.

Dr. Peter Chapman similarly found that "the Hunters Point site is 3.6x more degraded than the Treasure Island site and is, overall, the most degraded site." FEIS, Vol. I,, Technical Appendices, Appendix B, Part 5, Letter from Chapman, May 21, 1987, p. 1.

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After the second round of testing, both consultants again evaluated the data. Spies wrote:

> I repeated the analysis based on the sums of ranks of each sediment sample tested in the three bioassays. This exercise ranked all of the sediments based on the sums of ranks of each sample for all the bioassays. The following order, from most to least toxic emerged from that analysis (sums of ranks are in parentheses): HP-2A (4) > HP-4B (7.5) > TI-3E(9) > TI-6D (10.5) > Alcatraz (12) > ocean reference (16) > controls (18). As in my previous analysis, the Hunters Point samples are clearly more toxic than those from Treasure Island.
>
> The chemical analysis of sediments indicate that most of the metals were found in concentrations similar to those found in recent testing. For most all metals, Hunters Point sediments had the highest concentrations. (Emphasis added) FEIS. Volume III: Verification Testing of Dredge Sediments, Chapter IV. Attachment D - Spies, Robert B., letter of May 29, 1987, regarding Review of Homeporting Verification Program Data, pp. D2-D3.

Dr. Chapman came to the identical toxicity conclusion about Hunters Point, using his triad approach:

> Based on the chemistry verification data, the following order of decreasing contamination is apparent: Hunters Point > Alcatraz > Treasure Island > Alameda > Offshore. FEIS. Volume IV: Verification Testing of Dredge Sediments, Chapter IV, Attachment E - Chapman, Peter M. letter of May 26, 1987. "Application of the Sediment "Quality Triad Approach to the Verification Test Data: U.S.S. Missouri Homeporting", P. E-2.

I cite these quotes only to explain my belief the STR text could have more clearly asserted that two important Navy consultants found significant differences in toxicity in various sites of the Bay. To be sure, both Chapman and Spies in their letters included various caveats that the STR reports correctly indicating the uncertainty and limits of this data. However, I did not get the picture from the STR that Spies and Chapman were able to make some judgments which were very helpful to the public and decision makers in this controversy, such as that the toxicity at Hunters Point based on the bioassays "are clearly more toxic" than other Bay sites and both Hunters Point and Alcatraz were more toxic than offshore sites.

Similarly, there is discussion in the STR of evidence that grain size unduly influences the efficacy of the Rhepoxyinius test. This issue is not merely an interesting biological debate, but has had direct impacts on the most controversial of projects, the USS Missouri and the Port of Oakland, as indeed sediment from the project areas substantially impacted this organism. The claim that grain size dramatically mars the results, rendering the tests useless has been around for awhile. I attended a presentation at Region IX, EPA, a few years ago where Dr. Chapman described new data showing that grain size has some, but minimal effect. Grain size, Chapman said, could not account for the significant differences in toxicity demonstrated by the Rhepoxyinius test in the Bay Area.

CITIZENS FOR A BETTER ENVIRONMENT

The joint EPA--Corps Technical Review Panel on the Oakland project reviewed the test and described new data in press that indicated a "slight" response to grain size. The committee found that "the test results do suggest there is some cause for concern about the causes for these results and the potential for unacceptable adverse impacts from ocean dumping these sediments." Memorandum, "Oakland Harbor: Technical Review Panel Recommendations Based on Additional Sampling of Oakland Inner Harbor", May 11, 1988, pp. 1-2. The panel concluded that based on these results and other tests:

> there was some cause for concern about the possible behavior of these sediments in the ocean if they were dumped in an unrestricted manner, i.e., without capping or some other means of mitigation of their potential adverse toxic effects. . . . Therefore a conservative and environmentally protective approach is appropriate for the disposal of the suspect materials. . . . Id., at p. 2.

Again, I go into this detail only to illustrate why I felt in a few passages there was a certain view taken of the data and that a different weighting or emphasis may have been more helpful in the public understanding the current status and trends of data and data analysis. However, I am not seeking a further revision of the text. I believe that generally AHI did an excellent job, and the different emphasis I am suggesting here is the kind of micro-editing that should not be required before release of the STR. It is sufficient if this comment letter is included in the final draft.

I think we should bear in mind that the overall goal of the STR is to set forth the present knowledge on this environmental issue in a manner that is technically sound and informative for the public at large. While each member of the advisory committee may have a different view on certain passages in the text, I am comfortable that AHI has sufficiently explored all issues in a scientifically sound manner such that the public is alerted to the issues, the basic viewpoints from all sides, and the relevant data. That was their job and they have done it.

Advocates on all sides can take the document as a starting point and present their own judgment as to how to weigh and evaluate this data. CBE's view is that like the EPA-Corp committee reviewing the Oakland Harbor, a "conservative and environmentally protective approach" will require determining that some material cannot be disposed in water in an unrestricted manner. While the STR was necessarily restricted in taking a point of view, for the sake of the environment and the success of the Estuary Project I urge the consultants for the next stage to analyze the problems now posed from a conservative and environmentally protective approach. I believe that is the approach mandated by Congress for the Estuary Project's Plan.

Thank you for considering these comments.

Sincerely,

Alan Ramo
Legal Director

cc: Margaret Johnson, AHI

Marin Audubon Society Box 599 Mill Valley, California 94942-0599

October 20, 1989

Mike Monroe
SF Bay Estuary Project
P.O. Box 2050
Oakland, CA 94604-2050

RE: COMMENTS ON DREDGING AND WATERWAY MODIFICATION STR

Dear Mike,

While this STR is well written and informative, my overall impression is well expressed by a BCDC comment, "...the report appears to rely on the lack of proof to dismiss possible impacts." I would add that the report also uses the lack of proof to support making no regulatory decisions.

Summaries in Sections C and D emphasize the lack of knowledge about certain fates, evidences etc., and convey the impression that regulatory decisions should not be made until scientific study provides absolute cause-effect relationships and direct effects. In fact, this opinion is expressed directly on P. 249 last sentence, that the RWQCB demonstrated "a lack of patience ...to wait for science to 'fill' the existing data gap." This statement should be stricken. It is judgmental and in conflict with the discussion earlier on this page, that correctly states that scientific information is but one component of management decisions. Regulatory agencies are not required to "wait" until all conclusive scientific data is gathered. If we waited for science to answer all the questions raised in this STR, particularly in view of inadequate funding for scientific research, this estuary will be long dead.

Gaps in information should simply presented as a data gaps.

There should be a summary of what is "known" from existing studies. As I understand from this STR, there is a lot of dredge material floating around, much of which is contaminated, that much of the material disposed flows back into the estuary, that aquatic biota are capable of concentrating both metals and organic contaminants that are in the disposed of material etc.

I also would like to see a discussion of cumulative impacts that could occur if the projected dredging projects are disposed of in the estuary. Are impacts likely to get worse? Stay the same? Improve?

Are there not some provisions in the Clean Water Act and the Porter Cologne Act that apply to dredging and therefore should be discussed in this STR?

The STR should address whether dredging projects are subject to the environmental review, that most other potentially environmentally damaging "projects" are - CEQA and/or NEPA. With the exception of the Port of Oakland, I recall no other dredge and disposal project that has been so reviewed. As with other potentially environmentally damaging projects, the burden of proving that environmental impacts will not occur rests with those proposing the potentially damaging project. This document conveys the impression that it is up to someone else, regulatory agencies or perhaps the concerned public, but not dredgers, to provide conclusive scientific proof for each impact.

There should be some discussion in the AHI section of the following issues raised in P. Williams section: the role of tidal marshes as sediment sinks, and the possibility of increased suspended sediment in the water column as a result of the extensive loss of tidal marshes should be discussed in the (see Part II, Page 262).

P. 21 Has the Corps ever denied a permit for dredging?

P. 26 - responsibility for administering provisions of the Federal Endangered Species Act rests with the U.S. Fish and Wildlife Service, not Fish and Game.

It should be pointed out on P. 20 that many consider the duel responsibility of the Corps, as both dredger and issuer of dredging permits, to be in conflict.

What is meant by upland sites? Does, or has this category historically, this ever included wetlands, diked or tidal? Who makes the determination that the disposal site is upland - is this evaluated by an agency or is the opinion of the dredger accepted? Are the Corps records adequate to determine that no wetlands exist on any of the "upland" disposal sites?

There should be an attempt to contact the Corps directly to find out where material dredged from Alcatraz between 1984 and 1986 was disposed?

Several studies cited in this chapter indicate that dredge material comes back into the bay. This is of significance economically for dredgers and for all of us who pay taxes that cover the costs of the many Corps dredging projects.

There is an extra "and" on P. 136, line 8, para. 3, or else something is left out.

P. 164, **Sediment Toxicity** states that contaminants "may" be subject to photochemical degradation or metabolism that may not be revealed in bioassays. Is it also possible that they "may not," or that even if these processes occur there could still be impacts to aquatic organisms? In addition, is accepting the possibility that indigenous species having undergone genetic adaptations, acceptable in terms of the overall health of the estuary?

An "of" is missing from line 1, para. 2, P. 165. Also, eliminate "In" or change verb in para. 2, line 2.

P. 184, cautiously acknowledges that there will "Probably" be long term, or chronic effects of metals and organic contaminants on aquatic biota. However, there is no mention of higher order species, birds or mammals, that feed on the species discussed. This is particularly important because this estuary is major habitat for Pacific flyway species.

Is it necessary to know how natural and dredge material resuspension compare at this time?

P. 200 Reverse the-with in third line. Para. 1, the phrase "although somewhat localized in time and space" conveys the impression that the increased turbidity is not significant. Localized turbidity impacts are important to consider in themselves, and because they contribute to cumulative impacts that degrade the estuary.

Frequent disposal sites P. 205 are inhabited by opportunistic species. What is the significance of this? Should we be glad that at least some species live there? Or, does this contribute to the overall degradation of the estuary?

I suggest the following changes to the **Recommended Management Options:**

- The DSTR contains repeated references to inadequate records for disposal amounts, locations etc., to an extent that is quite surprising. A recommendation should be added to the management options that the Corps, and all other permitting agencies, develop a permitting, reporting, monitoring and enforcement system that ensures adequate data will be available for all dredge and disposal permits (including Corps projects and those issued under regional permits), and that includes projected and actual amount disposed, disposal locations, method, tide conditions for in-bay disposal, and time.

- I also suggest an option recommending adoption for the estuary of standards that are at least as firm as federal Ocean disposal standards. use of the Ocean Implementation Manual, but not allowing use of the disposal site as a reference site.

- Standards should be established for upland disposal sites that ensure that public health, and estuarine habitats are protected.

- 1.6 should be moved higher on list.

- Add an option that preparation and public distribution of EIR/EIS be required for all dredge projects.

- The impacts of some of the suggested management options may be significant so that it is unclear whether they would fulfill goal of the Estuary Project. My suggestions are:

Change 2.2.6 to Study the establishment of new in-Bay sites. 2.3.2 and 2.3.3 and 2.3.4 would or could have unacceptable impacts and should be eliminated.

Add a new first bullet under 2.4 suggesting a study of alternative disposal options that would have benefits to the estuary. The impacts of 2.4.5 and 2.4.6, 2.5.6 should be studied before specifically recommended.

Does "coastal" in 2.4.7 refer to the estuary? This should be clarified so that it does enable dredge material to be used to stabilize erosion in the estuary.

The statement on P. 250, para. 2, that whether a decline in body burden would be detectible or significant is unclear should at least be followed through with at least a brief discussion of the "wide range of variables" and cumulative impacts of aquatic disposal with other major estuary issues, particularly pollutants. Although qualified in the last sentence, the first sentence of para. 3 conveys a sense that management decisions which are made without "key scientific and technical" information are somehow inadequate. I suggest it be revised.

I agree with recommended studies, with the following changes:

- last line P. 250 add individuals after organizations. The qualifying statements in Para. 2, P. 251 and para. 3 should be eliminated. In other words, eliminate "efforts to maintain" and endeavor to develop."

- 4. P. 253. "....a routine biomonitoring program be established at all aquatic disposal sites in the Estuary." There are not that many. Since the Federal government is doing most of the work, it is in the best interest of the general public for them to conduct and fund such studies.

- Change 5. title to "in and **near**". The text indicates at.

- I disagree with the recommended emphasis on "Commercially-important species." Study has focused too long on species of

commercial interest, to the exclusion of species native to our estuary, so that we are not at the point where they may be becoming extinct with out our knowing much about them.

PHILIP WILLIAMS section is very good. Some Management Options should be included relating to his section.

P. 262 - Does wave action later resuspend "all" the recently deposited sediments?

Should the reference to not having a major earthquake since 1906 now be revised?

We agree that many flood control projects (there are a number of examples in Marin) are designed without full consideration of the effects of sedimentation; without consideration for the difficulties and expense of maintaining the systems without recognizing subsidence and future flood level; and that there is continued strong pressure for urban development in low-lying flood-prone land - all of which substantially increasing the risk of increased flood damage. I recommend that a management option(s) be included to address this issue. It could be done through a model ordinance, but I thing a more effective way, at least in SF Bay, would be to recommend expansion of BCDC's jurisdiction so that it covers all low lying flood-prone areas and that it strong provision to ensure projects are not developed in low lying, environmentally sensitive area.

The STR should recommend study of the use if dredge material to achieve marsh accretion. This seems a use that would have much benefit to the Bay particularly in view of the predicted rise in sea level and the erosion of many marshes that is taking place in the estuary.

Regarding the COMMENTS:

Why should the report not include a discussion of faulty or incomplete data, regulation or enforcement from or by agencies? This is important information for understanding of the status of this issue. Comment #19.

There should be an option recommended that the Suisun Bay site be discontinued for use because it is illegal and unregulated. This is not outside the scope of this STR (comment 20)

I disagree with the acceptance of a CORPS bias -- the bias of this report should be the estuary. The Corps may have the primary authority in regulation of the environmental effects of dredging and dredge material disposal, but that doesn't mean that their focus is the same as this project, or even that they adequately enforce their own regulations, particularly in view of their conflicting roles.

Thank you for the opportunity to comment.

Sincerely,

Barbara Salzman

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Eastern Contra Costa County

October 20, 1989

Mr. Michael Monroe
San Francisco Estuary Project
P. O. Box 2050
Oakland, CA 94604-2050

Dear Mr. Monroe:

Thank you once again for the opportunity to review the Draft STR on Dredging and Waterway Modification. I have attached my previous comments for your reference.

Those comments were not intended as simply informational. While the discussion in the STR of upland disposal may be technically accurate, it leaves out several significant aspects. Certainly, no official set of requirements for testing marine sediments that are proposed to be placed in the Delta has been promulgated. However, any project proposing Delta disposal must meet EPA and State water quality requirements and the CVRWQCB Basin Plan. Failure to mention this leaves the impression that disposal of dredged sediment in the Delta is not regulated. It is regulated and the report should list all the requirements.

Far more testing of the materials from the Port of Oakland Harbor was required than is indicated on page 228 (including toxicity tests). The report should indicate this fact. The report also fails to mention that detailed stability analyses should be performed before placement on levees, especially if the dredged material is contaminated.

Finally, the report's treatment of Delta disposal is cursory. If it cannot be more detailed and discuss testing requirements, regulations and areas of concern, then it should state that the review is cursory and that a more detailed treatment is required for complete understanding.

Sincerely,

Gregory Gartrell, PhD PE
Division Engineer

GG:ps
Attachment

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VIA TELEFAX

May 11, 1989

Mr. Michael Monroe
San Francisco Estuary Project
P. O. Box 2050
Oakland, CA 94604-2050

Dear Mr. Monroe:

Thank you for the opportunity to review the internal Draft STR on Dredging and Water Modification.

For the most part, I find the draft well written and documented. I would like to confine my comments to the discussion of uplands disposal, the area in which I have particular knowledge.

The discussion on Page 108 concerning the Port of Oakland is not entirely accurate. The last paragraph implies that the CVRWQCB allowed initial mixing to be taken into account. While the Port did apply initial dilution factors to its calculated discharge in their EIR, there is no basis for doing so. Ocean discharge regulations allow for initial dilution, but they specifically do not apply to estuaries or inland waters. Furthermore, the Port applied them incorrectly.

The CVRWQCB has in the past allowed dilution credit in a mixing zone for discharges involving chronic toxicity, on a case by case basis. There is no specific basis to applying them for discharge requirements involving specific chemical species.

Among the topics of concern in disposing of dredged material to the Delta are the fate of salt and contaminants in the material, the pollution of the Delta waters, and increased erosion and runoff from the levees (it often takes several years before vegetation will grow in the material). Any project must meet, among other State and Federal regulations, the CVRWQCB basin plan and Fish and Game requirements. Projects are also required to meet Subchapter 15 requirements regulating waste discharge to land.

The salt problem may be particularly serious, aside from the vegetation problems it causes, since it already poses a water quality problem in most parts of the Delta. Importing more salt may adversely affect the beneficial uses of the Delta water supply and may affect the ability of the State and Federal Water projects to fulfill their water quality and water supply functions.

Heavy metal contamination is of particular concern for fish and wildlife. A number of elements are found in dredged material t

high levels; these become mobilized as the material dries and oxidizes. The potential loading is very large, even for the Port of Oakland's small project. The CVRWQCB has estimated that the annual loading for some elements from this project may exceed the combined total of all point sources in the Bay-Delta estuary.

I hope you will find these comments useful. If you have any questions, please contact me at 415/674-8057.

Sincerely,

Gregory Gartrell, PhD PE
Division Engineer

GG:ps

DOUGLAS M. FRALEIGH, Director
F. I. HODGKINS, Deputy Director
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COUNTY OF SACRAMENTO

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October 18, 1989

Aquatic Habitat Institute
180 Richmond Field Station
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Subject: Comments on Second Draft Status and Trends Report on Waterway Modification

Sacramento County has reviewed the Second Draft Status and Trends Report on Waterway Modification. Generally, we found the report to contain a balanced presentation of available information on this important subject. We are concerned, however, that it is difficult to understand the implications of the identified management strategies on Delta and upriver communities. Sacramento County is very concerned that the Estuary Project process is being implemented in a manner where interested parties in the Delta are not being afforded reasonable access to the public process.

Section III of the report describes the roles of other government agencies and interest groups that influence management decisions and policies. In relation to the section's purpose and the inclusion of upland disposal as a long term management option, Sacramento County should be included as an agency that will influence management policies. This will occur because upland disposal sites should and will be classified as waste management units under California law. The establishment of any new waste management units in Sacramento County will require that Sacramento County grant discretionary land use entitlements.

Management Options 2.1.3, 2.4.1, 2.4.4, 2.4.5, 2.4.6, and 2.5.7 are all variations of upland disposal practices. Sacramento County is concerned, based on its involvement in the Port of Oakland project, that there is not a technical basis for concluding that upland disposal is an environmental sound disposal alternative for material which contains trace toxics. The obvious scenario is one where the trace toxics are released from the dredged material through surface runoff or subsurface water passing through the material as a result of Delta island drainage practices. Such waters are typically discharged back to the Delta channels. Under this scenario, the upland disposal site would become another source of water born pollutants which would be in conflict with options 1.6 and possibly 2.5.1. While the County agrees that upland disposal may offer the potential for significant benefits in terms of levee

reinforcement, the report should identify the lack of knowledge about the fate of pollutants in upland disposed dredged material as a data gap. The report should recommend that research be done to identify appropriate criteria for dredged material to be designated for upland disposal and to determine the appropriate control measures for pollutants from upland disposal sites.

Management options 2.4.4 suggest that dredged material which has not been dewatered is suitable for capping municipal landfills. This is not the case as the primary purpose of landfill caps is to prevent water from entering disposal sites.

Very truly yours

Douglas M. Fraleigh

Douglas M. Fraleigh, Director
Department of Public Works

DMF:FIH:bf

cc: San Francisco Estuary Project
P.O. Box 2050
Oakland, CA 94604-2050

Sue Ziegler
Mel Knight
Jim Dixon
Bob Shanks

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor
CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD—
CENTRAL VALLEY REGION
3443 ROUTIER ROAD
SACRAMENTO, CA 95827-3098

19 October 1989

San Francisco Estuary Project
Attn. Mike Monroe
P.O. Box 2050
Oakland, CA 94604-2050

REVIEW OF THE SECOND DRAFT OF THE "STATUS AND TRENDS REPORT ON DREDGING AND WATERWAY MODIFICATION IN THE SAN FRANCISCO ESTUARY"

Thank you for the opportunity to review the above cited report. Enclosed is an attachment with specific comments from staff.

If you have any questions, you can call Peter Haase at (916) 361-5624.

Jerrold A. Bruns

Jerry Bruns
Chief, Standards, Policies, and Special Studies Section

cc + enclosures:
Ms. Loretta Barsamian, U.S.EPA, Region IX, San Francisco
Mr. Tom Wakeman, U.S.COE, San Francisco District
Mr. Patrick Cotter, U.S.EPA, Region IX, San Francisco
Mr. Patrick Rutten, National Marine Fisheries Service
Mr. Steven Ritchie, San Francisco Bay Regional Board, Oakland
Mr. Steve Goldbeck, BCDC, San Francisco
Ms. Joan Patton, Oceanic Society
Mr. Alan Ramo, CBE, Berkeley

Jerry Bruns
19 oct comme

Memorandum

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD • CENTRAL VALLEY REGION

3443 Routier Road
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Phone: (916) 361-5600
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TO: WAYNE PIERSON
Chief, Central Regulatory Unit
JERRY BRUNS
Senior Land & Water Analyst

FROM: PETER HAASE
Water Resources Control Engineer

DATE: 17 October 1989

SIGNATURE: Peter Haase

SUBJECT: SECOND DRAFT, STATUS AND TRENDS REPORT ON DREDGING AND WATERWAY MODIFICATION IN THE SAN FRANCISCO ESTUARY

On 25 September 1989, we received a copy of the above cited report. The report has been prepared under an EPA Cooperative Agreement for the San Francisco Estuary Project by the Aquatic Habitat Institute (AHI) and Philip Williams & Associates LTD (PWA).

The stated goals of the San Francisco Estuary Project are:

1. Develop a comprehensive understanding of the environmental and public health values attributable to the Bay and Delta and how these values interact with social and economic factors.

2. Achieve effective, united and ongoing management of the Bay and Delta.

3. Develop a Comprehensive Conservation and Management Plan to restore and maintain the chemical, physical and biological integrity of the Bay and Delta, including restoration and maintenance of the water quality, a balanced indigenous population of shellfish, fish and wildlife, recreation activities in the Bay and Delta, and assure that the beneficial uses of the Bay and Delta are protected.

4. Recommend priority corrective actions and compliance schedules addressing point and non-point sources of pollution. These recommendations will include short and long-term components based on the best scientific information available.

The objectives of this report were to describe the present knowledge of dredging activities in the San Francisco Estuary. This was to include identifying trends in dredging and dredged material disposal, and reviewing information relating to potential affects that dredging and dredged material disposal might have on the ecosystem of the San Francisco Estuary. The report was written in two parts; part one of the report was concerned with dredging and dredged material disposal and was written by AHI, the second part discusses waterway modifications in the Estuary and was completed by PWA.

Based on my review I have the following comments and recommendations:

A. Section III.3. discusses in general terms the function of the State Water Resources Control Board (SWRCB) and the Regional Water Quality Control Boards. This section only identifies one SWRCB policy, the "Bays And Estuaries Policy". It is important to note that the RWQCBs regulate activities or factors which may affect the quality of waters of the State, this includes the prevention and correction of water pollution and nuisance. Projects (including dredging and dredge material disposal) are evaluated to determine if they can achieve water quality control requirements established by several State plans and policies.[1] I would recommend that these plans and policies be identified and discussed in the final report.

B. Upland disposal of contaminated and/or marine sediments in the freshwater portions of the Delta in the Central Valley Region will be regulated pursuant to the California Code of Regulations, Title 23, Chapter 3, Subchapter 15 (Subchapter 15), regulations pertaining to discharges of waste to land. Therefore, I would recommend that the report identify and discuss these regulations.

C. Information provided in Section V.C. on the fate of dredged materials is limited to dispersive aquatic disposal sites in San Francisco Bay. The report does not discuss the transport and/or fate of dredged material disposal in the Delta or at alternative in-bay disposal sites. Based on the stated objectives of the San Francisco Estuary Project, I

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[1] These include:

Water Quality Control Plans (Basin Plans)

SWRCB Ploicy for the Enclosed Bays and Estuaries of California

SWRCB (Antidegradation)Policy with respect to Maintaining High Quality Water in Califronia

Federal Antidegradation Policy

SWRCB Policy for Sources of Drinking Water

Proposed SQWRCB Pollutant Policy Document for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary

would recommend that the final report discuss the transport and fate of dredged material disposal from different disposal practices in both the Bay and Delta, and/or identify informational gaps that may warrant future studies or analysis.

D. Information provided in Section V.D. on the effects of dredged material disposal is limited to potential effects associated with aquatic disposal in dispersive sites in the Bay and is not applicable to the Delta. This section provides a literature review of the physiochemical aspects of sediment contamination and contamination remobilization, the long-term release of contaminants, loading estimates of contaminants associated with dredge material disposal, the bioavailability of sediment-borne contaminants, sediment toxicity and the toxicity of remobilized contaminants.

The section provided on the physiochemical aspects of sediment contamination, contaminant remobolization and long-term release of contaminants is directly applicable to the disposal of dredged spoils in the Delta; however, the report only discusses these processes associated with the potential affects of disposal in the Bay. I would recommend that the final report provide a literature review of available studies on the impacts to water quality from the disposal of contaminated and/or marine sediments upland and in freshwater environments, such as the Delta.

This section provides loading estimates for contaminants from dredging and disposal for the Bay only. It is important to note that available dilution in the Delta may be significantly less than that available in the Bay. Therefore the loading of additional contaminants (i.e, salts, metals and organics) in the Delta from dredging projects could result in significant impacts to water quality. I would recommend that the final report discuss the water quality trends in the Delta, the potential impacts associated with additional loading of contaminants in the Delta, and/or identify informational gaps that may warrant future studies or analysis.

The remainder of this section is limited to discussing the potential impacts of dredged material disposal to marine organisms (with the exception of striped bass, an anadromous fish). Therefore, this information is not applicable to the Delta. Based on the stated objectives of the San Francisco Estuary Project, I would recommend that the final report discuss the potential effects of dredged material disposal on the beneficial uses of water in the Delta, and/or identify informational gaps that may warrant future studies or analysis.

E. Per Section V.E.1.B., the CVRWQCB has required both near and far-field hydrodynamic (and physical) modeling to describe plume dispersion and mixing zones

associated with the disposal of dredged materials in the Delta. Future dredging projects may also be required to determine the characteristics of plumes associated with the disposal of dredged sediments.

F. In addition to the testing procedures identified in Section E.3.B., the Port of Oakland has completed toxicity tests evaluating both acute and chronic toxicity of simulated effluents using EPA Method 600/4-89-001 (Short-term Method for Estimating the Chronic Toxicity of Effluent and Receivng Water to Freshwater Organisms). The Port and CVRWQCB staff have also completed several bulk sediment and extraction tests on reduced and oxidized harbor sediments in an effort to determine the long-term release of contaminants. Pursuant to the requirements of Subchapter 15, the Port of Oakland has been required to submit numerous plans and reports to fulfill the requirements of a report of waste discharge. To date the Port of Oakland has not submitted final plans and reports as required; however, they requested issuance of conditional requirements so that they could develop sufficient designs and plans to comply with the conditions of the waste discharge requirements. Conditional waste discharge requirements were adopted by the Regional Board in July 1989 (a copy of these requirements is attached). The requirements include specifications, provisions, prohibitions and limitations for disposal of the dredged spoils, and for the protection of surface water and ground water quality in proximity to the disposal site. The requirements also include a fairly extensive monitoring and reporting program, including the monitoring of chemical constituents in both surface and ground water, conducting both acute and chronic toxicity tests, bioaccumulation studies, and monitoring of the disposal site for several parameters (i.e, sediment transport, tracking the establishment of vegetation and monitoring bioaccumulation by plants).

Currently, the Port of Oakland and the USCOE are conducting long-term sediment tests to evaluate the potential release of contaminants from this material if placed upland. The USCOE may be information available by the end of November. The Port of Oakland has not indicated if and when their data will be available. I would recommend that this information be incorporated into the final report or at minimum noted for future review by interested parties.

As mentioned above, upland disposal of contaminated or marine sediments will be regulated under Subchapter 15. Pursuant to these regulations a full waste characterization is required, therefore, we will be requiring project proponents seeking project approval to conduct both short and long-term sediments tests, similar to the

procedures discussed by Lee and Peddicord (1988)[2] for consideration of Upland disposal in the Delta.

G. In Section VI.B.1.A. the USCOE staff states that heavily contaminated material from the Phase II Oakland Harbor Project will be placed on-land. I would recommend that this be rephrased to say "the USCOE may propose to place heavily contaminated material upland; however, this is subject to the approval of both state and local authorities (i.e, the RWQCBs, and local health and planning departments)". As noted in a previous section of the report the USCOE has limited authority regarding the disposal of dredged sediments on-land.

H. Section VI.B.2. provides a limited discussion of future trends in projected dredging and disposal in the Delta. A large proportion of dredged material is disposed in the San Francisco Bay as compared to the Delta; however, with the increasing pressure to reduce the amount of material disposed of in the Bay, several proposals and studies are currently being developed evaluating the feasibility for disposal of San Francisco Bay sediment (marine sediment) into the Delta. I would recommend that the final report discuss this current trend.

The Delta has approximately 150 marinas and related facilities. I would estimate that approximately 0.10 - 1.0 million cubic meters/year of maintenance dredging occurs from these facilities. Recently submitted data for a number of maintenance dredging projects has shown enrichment of sediments with heavy metals, TBT and PAHs, and has required the project proponents to place the dredged spoils into confined disposal areas. There are also a number of other new dredging and disposal projects proposed in the Bay and Delta, in part these include the, Department of Navy projects at Naval Air Station, Alameda and Naval Supply Center, Oakland, the Department of Water Resources North, South and West Delta Water Management Programs, and the Harbor Marina project. I would recommend that AHI review the recently completed Checkpoint 3 Report (dated 1 September 1989) completed by Ogden Beeman & Associates for the USCOE, San Francisco District, entitled "Investigation of Dredged Material Disposal Alternatives in the Sacramento/San Joaquin Delta for Sediments Dredged from San Francisco Bay" to identify current and proposed dredging projects in the Delta.

2 Lee, C.R. & R.K. Peddicord, 1988, Decision-Making Framework for Management of Dredged Material Disposal, In Salomons, W. and V. Forstner (eds), 1988, Environmental Management of Solid Waste, Dredged Material and Mine Tailings, Springer-Verlag, New York

I. Per Section VI.C.2.5.7., I would recommend that this sentence be rephrased to state, "establish upland sites for the disposal of contaminated sediments where the sediments are confined and/or leachate is treated to prevent the release of contaminants from the disposal site".

J. The long-term management options discussed for alternative disposal options appear to relate to the disposal of San Francisco Bay sediments in the Delta. However, as cited above the report has not identified potential impacts associated with this disposal option. Therefore, I would recommend that the final report discuss short and long-term management options that are well founded, and if these options are not well founded then research needs and/or data gaps should be discussed relative to the identified management option(s).

In summary, the first part of the report prepared by AHI contains only limited information on dredging projects completed in the Sacramento and San Joaquin deep water ship channels. The report does not provide any technical information discussing the potential impacts associated with the placement of the dredged material upland. The information provided discussing the effects of dredging and disposal is limited to activities in the San Francisco Bay. Therefore, the information provided does not apply to the Delta. The report does not adequately discuss the current trend in dredging and dredge material disposal in the Delta, such as the placement of bay sediments in the Delta. The report does not adequately identify the potential problems associated with these types of projects or discuss actions taken by regulatory agencies to assess and control these projects. Similarly, the management options provided by the Dredging Subcommittee may not represent the management needs in the Delta. In conclusion, part one of this report clearly does not meet the objectives of the San Francisco Estuary Project, as stated above.

PHH

ATE OF CALIFORNIA—THE RESOURCES AGENCY

GEORGE DEUKMEJIAN, Governor

EPARTMENT OF FISH AND GAME
16 NINTH STREET
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(916) 445-1383

October 24, 1989

Mr. Michael Monroe
Technical Program Manager
San Francisco Estuary Project
P.O. Box 2050
Oakland, CA 94604-2050

Dear Mr. Monroe:

Environmental Services Division staff have reviewed the second draft of the Dredging and Waterway Modification Status and Trends Report and we compliment you on correcting many of the deficiencies in the initial draft that were brought to your attention during the review process. However, in our view there continues to be significant flaws in this draft which we hope will be rectified in the final report. Our comments on the more serious shortcomings follow.

In describing the Department of Fish and Game's role in dredge material management decisions and policies (page 26), the Report fails to cite our relationships with the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) and San Francisco Bay Conservation and Development Commission (BCDC). As a fellow State agency and the authorized custodian of the State's fish and wildlife resources, the Department has demonstrated a history of involvement in key decisions and policies of both the RWQCB, BCDC as well as the U.S. Army Corps of Engineers (USCOE). The Department's key authorizations are contained in the State Fish and Game, Public Resources and Water codes as well as the Federal Fish and Wildlife Coordination Act.

The Report states (page 31) that during 1986 and 1987, 38 percent of the total volume dredged in the estuary was from non-federal projects and goes on to make the assumption that a "similar distribution of federal and non-federal dredging occurred in the past." Nevertheless, this figure is not applied in the remaining portions of the "Historical Trends Section". Consequently, disposal volumes through 1985 are portrayed as being less than what was actually released. We believe that the reader would have a more realistic sense of post-1986 activity if this figure were applied more thoroughly. Also, in the "Historical Trends Section" (page 58), it would be useful if the results of the disposal of sediment at the Farallon Island's test site during the Dredge Disposal Study were described.

While discussing the monitoring of disposal barges in 1986 and 1987 (page 78), it is reported that data from April and May 1987 are missing. An explanation as to why this important data gap occurred would be useful. Also, no information is presented as to why the various numerical models on dredge material disposal (pages 108 to 111, and 134) currently employed by the USCOE have not been field verified as suggested.

References to the precise onset of the slurrying requirement at the Alcatraz site (pages 120 and 194) continue to be unnecessarily vague. This piece of information is of considerable importance when evaluating fishery impacts.

In summarizing the discussion on the toxicity of remobilized contaminants (page 184), a statement is made that "there is no evidence that 'biomagnification' . . . is occurring in the various levels of the food web of the San Francisco Estuary." It is difficult to understand how such a conclusion can be drawn in light of a previous remark (page 158) that "Little is known regarding food webs in the Estuary . . . ." A more appropriate summary statement would be that more work is needed before biomagnification can be discounted as a factor of toxicity.

The Department commented on the previous draft regarding the failure to discuss the impacts of frequent disposal operations on increased suspended sediment concentrations in central San Francisco Bay. Although this has been corrected for the most part, the frequency element was omitted from the statement summarizing those factors that determine these concentrations (page 191). This element must be included in the summary of factors affecting concentrations.

Our most substantive concerns continue to be related to the discussion of the effects of suspended sediment concentrations on the biota, particularly fisheries. The following comments are directed towards that portion of the Report:

1. It is mentioned on several occasions (beginning on page 191) that disposal impacts need to be considered in the context of the natural suspended sediment levels and their temporal variation. We do not disagree with this conclusion but assert that spatial variation (e.g., central San Francisco Bay) may be equally important.

2. Department data on party boat landings for 1988, which showed continued declines in catch, should be included here (page 194).

3. Data on page 194 regarding average disposal volumes at Alcatraz are incorrect. The average disposal for 1986 and 1987 at that site according to Table 12 (page 89) is

4.7 million cubic yards, not the 2.3 million cubic yards reported in the text. Additionally, since neither Table 5 nor Table 12 account for the approximately 38 percent increase that would come from considering permitted projects, the figure representing disposal increases after 1985 is equally incorrect.

4. Comments regarding the SFBRWQCB's Basin Plan Amendments which state that the new disposal limits at Alcatraz will "avoid any potential impacts upon fish, migration routes, or fish spawning habitat" (page 194) are incorrect. Impacts may be lessened somewhat, but to imply that they will be avoided is certainly a gross overstatement.

5. We agree with the SFBRWQCB and the authors of the Report that catch-per-unit-of-effort (CPUE) is difficult to apply to recreational fish catch, particularly party boat landings (page 196). As a result, we have used total catch (monthly or annual) to distinguish trends in this fishery as they relate to disposal at Alcatraz. This data should be considered in the Report.

6. The Report states (page 199) that "there are not adequate data to support or refute the contention that disposal of dredged material has increased turbidity in Central Bay and resulted in an adverse impact on fisheries." We disagree! We suggest that if one takes into account the numerous observations made by anglers in central Bay, as well as the available fisheries data, the burden of proof shifts to the USCOE and other users of in-Bay disposal sites to demonstrate that disposal activities are **not** having adverse effects on fishery resources and their use. The Report must be changed to reflect this shift in burden of proof!

7. The discussion on pages 200 and 201 should incorporate the element of disposal frequency as previously mentioned.

The "in-Bay disposal" component of the "Short-Term Management Options" should contain a recommendation for specific volume limitations.

The absence of fisheries impacts in the "Data Gaps" section (pages 245 to 248) contradicts previous statements, unless we are to assume that adults are considered "sensitive life stages"; this is usually not the case. The need to identify these impacts is included in the following section on recommended research.

Lastly, regarding additional research needs, we feel that some of the comments made regarding the role of dredge material disposal as a source of contamination in the estuary (page 250) are not totally unbiased. We also recommend that turbidity measurements be included in disposal site monitoring efforts (page 251).

In conclusion, the Report must be amended to reflect our concerns if there is to be agreement and direction concerning the future environmentally sound practices of dredging and waterway modification of San Francisco Bay.

In addition to these comments, there are some technical errors in the text which we can identify for you. For this information, or for any questions you may have regarding our comments, please contact Mr. Robert N. Tasto of my staff at the Department's Marine Resources Laboratory, 411 Burgess Drive, Menlo Park, CA 94025, telephone (415) 688-6360.

Sincerely,

Don Lollock

Donald L. Lollock, Chief
Environmental Services Division

cc: Mr. John Beuttler, United Anglers-Berkeley

Mr. Barry Nelson, Save San Francisco Bay Association-San Francisco

ATE OF CALIFORNIA—THE RESOURCES AGENCY

GEORGE DEUKMEJIAN, Governor

EPARTMENT OF WATER RESOURCES
ENTRAL DISTRICT
251 S STREET
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95816-7017

OCT 3 1 1989

Mr. Mike Monroe
San Francisco Estuary Project
P. O. Box 2050
Oakland, CA 94604-2050

Dear Mike:

This is in response to your request of September 22, 1989 for comments on the draft report "Dredging and Waterway Modification in the San Francisco Estuary". I have been asked to coordinate the Department's review.

The following are a few specific comments which apply to the waterway modification portion of the report (we did not review the dredging section):

- The authors exaggerate the impact of Central Valley water development on flood flow and sediment reductions. To be sure, the dams do reduce flood peaks and store a lot of winter and spring season water. But, at the same time, channelization in the Valley speeds winter runoff into the Delta and Bay. It is not clear how these effects balance out. In its natural state, floods overflowed banks, deposited silt, and slowly drained out to the Bay. Even though we cannot quantify it, the channelization factor should be recognized.

- The Central Valley Project (page 8 and elsewhere) seems to be pictured as the villain. The CVP is only part of the cause. Sediment production at Shasta was quite low and Folsom is the only other large CVP reservoir in the Sacramento River Basin. We are still getting far more sediment deposition that wanted in the Sacramento River Flood Control Project. It has not been shown that there has been a reduction in sediment supply.

- On page 267, it is not clear that the tidal prism would change that much if some Delta islands flooded. The prism is also controlled by the Carquinez and Chipps Island constrictions.

- On sea level rise, we agree that current rates are about 0.7 feet per century (at the Golden Gate gage). Department staff is skeptical about the forecasted acceleration in sea level rise to 1 meter in a century.

- On page 260, first paragraph under Section D, the author states that "..[a]pproximately half of the average annual inflow is being diverted...." citing testimony prepared for the Bay-Delta Hearings. We do not believe this to be an accurate portrayal of the Hearing record.

I have also attached a copy of the text with some editorial and technical comments made by Stein Buer, an engineer in the Department's Division of Planning.

If you have questions regarding these comments, please call me at (916) 322-7165.

Sincerely,

Randy

Randy Brown, Chief
Environmental Studies Branch

Attachment

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

REPLY TO
ATTENTION OF

CEWES-EP-D (70-1r) 7 Nov 89

MEMORANDUM FOR Commander, U.S. Army Engineer District, San Francisco
ATTN: CESPN, 211 Main St., San Francisco, CA
94105-1905

SUBJECT: DOTS Request for Assistance

1. Enclosed is a Memorandum for Record in response to your request for assistance in reviewing the San Francisco Estuary Project report entitled, "Second Draft, Dredging and Waterway Modification Status and Trends Report." This response was developed by Drs. Michael Palermo and Thomas Wright and Mr. Francis Reilly, Jr., of the Environmental Laboratory and Mr. Larry Hauck of the Hydraulics Laboratory at the Waterways Experiment Station.

2. We appreciate the opportunity of assisting you through the DOTS Program, and if you have any questions, please call Dr. Wright at 601-634-3708.

FOR THE CHIEF, ENVIRONMENTAL LABORATORY:

Thomas R Patin for

Encl

ROBERT M. ENGLER, PhD
Manager, Environmental Effects
of Dredging Programs

CF: (wo/encl)
Palermo, EE
Wright, ES-R
Reilly, ES-R
Hauck, HE-S

CEWESEE-P 20 Oct 89

Memorandum for: Dr. Tom Wright, ERSD/EL

From: Dr. Michael R. Palermo, EED/EL

Subject: Review of Aquatic Habitat Institute (AHI) Report Entitled "Second Draft, Dredging and Waterway Modification Status and Trends Report", DOTS Request 90-001

1. As you requested, I have reviewed pp. 106-133, 186-200, and 249-253 of the subject report. I also gave copies of pp. 106-133 and 249-253 to Mr. Bill McAnally, HL, since they pertained largely to modeling work for the Bay. The HL comments will be furnished to you separately.

2. My general comments are as follows:

a. The portions of the report I reviewed consist of a literature review of past studies pertaining to dredging and disposal in the Bay with interpretation by AHI and some recommendations for research. AHI generally did a good job of describing the results of past studies, but seemed to stretch those results to support a position of environmental concern regarding Bay disposal.

b. The main concern as portrayed by AHI in this report was the contribution of dredging to resuspended sediment/turbidity in the Central Bay and its effect on fisheries. Throughout their review of the literature and recent study results, AHI correctly describes the sediment resuspension due to open water disposal as short-term and localized. However, they have included in their interpretation hypothetical statements and/or estimates of suspended solids loadings which are at best severely overconservative and at worst are irresponsible.

c. AHI describes the results of several recent field studies conducted for in-Bay disposal operations. They have made statements to the effect that such studies are not "conclusive", and have made other statements to the effect that more precise answers to the questions would be a "challenge". AHI then makes recommendations for additional research. I have no doubt that the recommended research activities would add to the data base concerning sediment transport processes in the Bay and the fate of dredged material placed at in-Bay sites. However, even if all the additional research was completed, I believe we would be no further along in resolving the issues. There will always be concerns and questions from those interests who are now opposed to in-Bay disposal. The Corps has already made a good faith effort to conduct extensive evaluations of our operations in the Bay. The technical information we now have does not indicate that any unacceptable adverse impact can be attributed to our operations. I believe the time has come to stand firm on the Federal Standard.

3. Specific comments are as follows:

p. 109 para. 2. Results of the WES disposal models (DIFID, DIFHD, and

DIFCD) should not be described as "preliminary". The reference for this quote is a 1976 publication. Much work has been done since that time. The models have been verified at a number of sites under varying conditions and have been shown to accurately simulate the processes governing the short-term fate of material placed in open water.

p. 111 para 2. I am confident that sensitivity analyses have been performed for the models and are documented in existing publications.

p. 111 last para. The reference Bowers and Goldenblatt (1978) is not given in the bibliography. The citation Truitt (1986a) should be Truitt (1986b). There are other references which give more detailed descriptions of the short term behavior of material, which leads me to believe that either an extensive search of the literature was not made or the authors did not summarize all available literature on this topic area.

p. 113. last para. This portion of the report should give an explanation as to WHY a mound developed at Alcatraz. This is an especially important point because later sections of the report imply that there are potential adverse effects due to increased turbidity resulting from the slurry requirement at Alcatraz. As I have previously commented on an earlier AHI report, the slurry requirement should be put into historical perspective. Alcatraz has been an active site since before the turn of the century. The predominant use of the site was for hopper dredge disposal, and material was in a slurried state. In recent years, because of an increased use of mechanical dredges and bottom dump barges, the materials dumped at the site were in a more cohesive state and did not disperse as effectively as in past years. Some of this recently dredged material was new work, and some debris was also placed at Alcatraz, aggravating the problem. The slurry requirement really returned the disposal operations at Alcatraz to what they had been historically. If fishing success is directly affected by the slurry requirement, we should see poor fishing prior to about 1980, a jump in success from about 1980 to 1986, then another decline. The fishing data as given in this report does not indicate that trend.

p. 131 para 2. The statement that redredging material which is redeposited in channels adds to overall costs of dredging is not necessarily true. Sediment transport processes acting throughout the Bay cause a net erosion in some areas and a net deposition in others. For the most part, Bay disposal sites have been selected purposely because they are "dispersive", i.e. are erosive areas. Even if no dredged material were placed at these locations, they would remain erosive, and other materials from those same areas would still be eroded and later deposited in the channels.

p. 131 para 3. This paragraph is a real trip! The only fact that I could get out of all this and later paragraphs is that SOME PORTION of the material we place at in-Bay sites finds its way back to the channels. To me, quoting a crude budget study conducted in 1965 is an example of stretching the available literature to make a point, in this case that the extra cost of ocean disposal is justified. I would be greatly surprised if the currently available sediment transport data indicates that 67% of the material we dredge from all channels in the Bay is redeposited in the channels.

p. 186 last para. A figure of 3500 mg/l or 3.5 g/l of TSS in hopper overflow would be appropriate only when dredging a sand. Overflow for a fine maintenance sediment would be at least an order of magnitude greater.

p. 187 para 2. The statement is made here that the resuspended sediment concentration resulting from operation of a clamshell dredge is lower than for a hopper dredge. This should be clarified by stating whether or not overflow is considered. The operation of a hopper dredge with no overflow results in less resuspension that for a clamshell dredge with no overflow of the barge. Overflow of either a hopper dredge or of the barge used with a clamshell dredge adds significantly to the degree of sediment resuspension. A similar statement made on p. 191 para 2 should also be clarified.

p. 187 para 3. The statement that only a small fraction of the dredged material representing the least dense portion remains in the upper water column should be clarified. The entire volume released is not dispersed and the entire fine fraction is not initially suspended. Most of the finer material is quickly carried to the bottom with the overall mass of the material. Only a small fraction of the total volume released is initially suspended in the upper water column (less than 5% based on field studies) and only the fine fraction of this material remains suspended long enough to be dispersed off-site.

p. 190 para 3. I agree that "accumulation" of suspended sediment in the water column could occur with closely spaced dumps. However, the effect of closely spaced dumps is not purely additive. The concentration of material in the water column from any given dump is steadily reduced by sedimentation and is diluted by mixing and dispersion. These facts are ignored by later hypothetical examples.

p. 196. first full para. This paragraph says it like it is! We will never be able to "find" the effect of dredging-induced turbidity within the context of the complex processes within the Bay, except within the immediate vicinity of the dump. If we all can agree that "there is no adequate scientific data to support or refute" the concern of dredging-induced turbidity, then why should the taxpayers be saddled with the higher costs of other alternatives when no benefit can be shown??

p. 199. para 2. All field data to date indicates that less than 5% of the material is initially suspended in the upper water column. Therefore the SAIC assumption of 10% is VERY CONSERVATIVE. Further, it must be noted that the material initially resuspended is dispersed but does not all remain in the water column indefinitely. Sedimentation processes are constantly removing the material from the water column.

p. 199. para 3. I agree that there may be an error in the SAIC calculations, but I also contend that there may be an error in the AHI calculations. According to my own calculations (see encl 1), a TSS concentration of 8 mg/l results from the complete mixing of 10% of a 4000 m^3 dump of 1.3 g/cc density material in a volume of water with 0 mg/l background TSS 1 km square by 25 m deep. However, please note that this hypothetical

example ignores the sedimentation process which is constantly removing material from the water column.

p. 200. para 2. I am greatly disturbed by this paragraph! If I read this correctly, AHI has developed a hypothetical "worst case scenario" in which 25% of 41 daily dumps is assumed to be suspended and remain suspended, and subsequent dispersion throughout the Central Bay results in a 43 mg/l elevation in water column TSS. This is truly an example of stretching information until it breaks in order to make a desired point. I would agree with AHI's own statement in this paragraph that such numbers are "suggestive". AHI has assumed a magnitude of initial suspension over 5 times greater than actually occurs and has assumed that all material initially suspended from all dumps remains suspended (for up to 24 hours). At best this scenario is grossly conservative. At worst, publication of such numbers is irresponsible.

p. 251 para 3. It seems that AHI is recommending here the development of sediment criteria similar to PSSDA. We have been through this ordeal before, but if they must do something, at least they state that such criteria would be used to "define the point at which a sediment must be subjected to biological and chemical tests", i.e. a reason to believe that contaminants are a potential problem.

p. 252 para 1. I believe we are investigating such "causal mechanisms" under the LEDO program.

p. 253 para 2. I agree that monitoring of suspended sediment levels throughout the Bay prior to and during disposal periods may at least settle the question on the relative contribution of dredging operations. This would not necessarily be overly expensive.

CF:
Patin/Engler, EEDP/EL

Michael R. Palermo, PhD, PE
Research Civil Engineer

Routing:
C/EED, Palermo, EED

SUBJECT: Hypothetical mixing example	COMPUTED BY: MRP	DATE: 2 Oct 89	FILE NO.
	CHECKED BY:	DATE:	SHEET NO.

Assume 4000 m^3 barges, 1.3 g/cc density material.

10% or 400 m^3 of material is mixed.

1.3 g/cc equates to 480 g dry weight solids per liter volume. (Assuming $G_s = 2.6$)

$400\ m^3 \times 480\ g/\ell \times 1000\ \ell/m^3 = 1.9 \times 10^8$ g solids mixed

Volume of water = $1000\ m \times 1000\ m \times 25\ m = 2.5 \times 10^7\ m^3$

$1.9 \times 10^8\ g / 2.5 \times 10^7\ m^3 = 7.6\ g/m^3$ call $\underline{\underline{8\ mg/\ell}}$

So, 10% of 4000 m^3 of material 1.3 g/cc density mixed in 1 km^2 × 25 m water volume results in an 8 mg/ℓ concentration of TSS. (approximate).

$\underline{\text{Check}}$ 1.3 g/cc = 480 g/ℓ

$$\text{density} = \frac{W_T}{V_T} = \frac{W_s + W_w}{V_T}$$

$W_s = 480\ g \qquad V_T = 1\ \ell = 1000\ m\ell$

$V_s = W_s/G_s = 480\ g/2.6 = 185$ mℓ solids

$V_w = V_T - V_s = 1000 - 185 = 815$ mℓ water

$W_w = 815\ g$

$$\gamma = \frac{W_T}{V_T} = \frac{(W_s + W_w)}{V_T} = \frac{(480 + 815)}{1000} = 1.3$$

WES FORM NO. 1253
REV OCT 1968

Fig. 1

CEWES-ES-R (70-1r) 6 NOV 89

MEMORANDUM FOR RECORD

Subject: Review of Aquatic Habitat Institute (AHI) Report Entitled "Second Draft, Dredging and Waterway Status and Trends Report", 12 Sep 89.

GENERAL COMMENTS

1. I have reviewed pages 135-185, 200-207, and 249-243 of the subject report. I believe the the AHI has done a resonaable job of reviewing the considerations of contaminants associated with dredging activities and dredged material disposal. I have provided specific comments below.

SPECIFIC COMMENTS

pg.136..1.*Metals* 1st paragraph. line 7-8. This sentence starts to say something important about the relative merits and problems associated with testing strategies, but the sentence ends prematurely. The paragraph abruptly changes sense. It is important to know the strengths and weaknesses of the assessment methods mentioned in this paragraph, especially when the last mentioned "field studies of populations..." is so expensive, and so unlikely to provide useful data.

pg.137..2nd paragraph. line 2-3. While trace elements *may* exist in more mobile forms under anoxic conditions, under extremely anoxic conditions, the trace elements may be highly immobile (See Gambrell et al,1980. ENV. SCI. & Tech. 14(4):431-436.)

pg.137..4th paragraph. Trace element contaminants associated with pore waters are also the most likely to precipitate out of solution as oxides and hydroxides of Fe and Mn due to the dredging process.

pg.137..5th paragraph. The technique of sequential leaching to predict bioavailability is problematic. The technique has not been shown to reproducibly predict the bioavailability of trace elements.

pg.151..2nd paragraph. The statement was made that as co-precipitates of Fe and Mn age, they become much less effective scavengers. While this may be true, it intimates that either release occurs, or that free trace elements will not be scavenged by Fe and Mn oxides and hydroxides. Release, then, does not occur (on a mass basis). New releases of trace elements will be accompanied by releases of Fe and Mn, and, subsequently, by new formation of oxides and hydroxides of Fe and Mn.

pg.151..3rd paragraph. "Under such conditions..dissolution of amorphous hydroxides of Fe and Mn may take place." The conditions mentioned "74cm deep...reduction of oxides to sulfides", trace elements will be bound more tightly (sulfides), and will be even less bioavailable (74cm deep and more tightly bound).

pg.152..*D.LOADING ESTIMATES...etc.* 1st paragraph. The point is well taken, that double counting may occur. In the second sentence the document allows that contaminants in dredged sediments *may* have originally been derived from other quantified sources. In fact, contaminants in dredged sediments *certainly* were derived from other sources in that dredging does not increase the amount of contaminants.

pg.154..(iv) adsorbed, not absorbed.

pg.154..last paragraph. The document makes a good point concerning the potential differences between 'new-work' and maintenance dredging in contaminant release patterns, but ends the paragraph pointing out the worst case "contamination from historic activities ..Todd Shipyard site in Oakland Inner Harbor". This specific worst-case would be provided for by the Tiered evaluation procedure, and the historical "reason-to-believe" in Tier I. In the general case, any new-work would most probably not contribute additional contaminants to the Bay, and may contribute additional binding sites to sequester contaminants.

pg.157..3rd paragraph. Bioconcentration factors are explained for organic contaminants as organism concentration *versus* water concentration. This gives an alarmingly distorted idea of the bioconcentration factor for neutral organics. BCF should be expressed with respect sediment loads of neutral organic compounds.

pg.159..1st paragraph. "Zn is an essential element, and is well regulated by most organisms." This statement is true but leaves out the other two trace elements also being discussed. Both Cu and Cd are also well regulated by the metallothionein system, which is present in most organisms.

pg.159-164.. Some interesting points are made throughout this section. Few local studies have dealt with bioaccumulation due to dredging activities. These studies show the effect of climatological factors to be greater than any effect of dredging (with the exception of DDE in one study). There appears to be little or no verifiable food-chain effects, or bioconcentration. Cain and Luoma (Estuarine Research Federation 1989), though not dealing specifically with dredged materials, have developed a model to predict Cu and several other trace elements levels in benthic organisms. Their work could shed some light here.

pg.164-172..The document reviews the results of several different bioassays and cites their lack of agreement in findings. It is important to realize that bioassays of different organisms that give identical responses should be suspect. Each bioassay assays a different organism, or different endpoint(reburial, weight loss, death). Each organism may respond to a toxicant in different ways, and therefore at different effective concentrations. Lack of concordance among bioassays should not be surprising. The document also cites an editorial by Spies (Mar. Env. Res. 1989, in press) which faults the cited bioassays, the fault being the inability to discriminate between sediment grain-size effects and contaminant effects. This is a point well taken. WES currently has proposed to the San Francisco District several studies to address this problem.

pg.173..3rd paragraph. The document presumes without citation or data that there is a decline in fisheries productivity in the San Francisco Bay Area. This assumption can not be made without documentation.

pg.174..2nd paragraph. The list of metals with the greatest potential toxicity (Hg,Cu,Cd,Zn) that are involved in metallothionein metabolism neglects to mention Ag. Ag is a metallothionein-metal, and has potential toxicity at levels found in sediments in the San Francisco Bay.

pg.175. 1st paragraph. While most protein associated metals do have a higher trans-gut assimilation efficiency, they also tend to be routed to the kidney, and eliminated much more rapidly that free-ion metals.

pg.176. last paragraph. According to the document, the potential accumulation of metals cannot be modeled, therefore, extensive testing will be necessary. It may be necessary to perform extensive testing to validate predictive models, but is outside of the requirements of US EPA regulations. The tiered testing approach is based on a 'reason-to-believe,' followed by effects-based testing. If no biological effect can be measured, why must extensive sampling be performed?

pg.184. 1st paragraph. The document states,"disposal of PAH-contaminated dredged material at dispersive sites in the estuary will almost certainly cause increased availability of PAH to filter-feeding and deposit-feeding biota." This may or may not be the case. McFarland and Clarke (1987. TN EEDP-01-8, US Army Engineers) demonstrate that percent total organic carbon (%TOC) is a good predictor of neutral organic bioaccumulation. Without knowing the %TOC nothing can be said about the potential availability of PAH's from contaminated sediments. Futher, the source of PAH's to dredged materials also contributes to the overall loading of PAH's in San Francisco Bay

pg.185. 1st paragraph. The document questions bioassays that are currently used, and those proposed, because these assays give equivocal results, or because these assays may be assays for environmental effects different than the effects of the contaminants in question. First, the document has not reviewed proposed bioassays, and should make no statements concerning them. Second, the assays in question do address environmental effects, as they are mandated to do. The effects may only be "related to" the contaminants, but they are measurable effects.

pg.185. 2nd paragraph. It has not been shown in this report that dredged-material-derived contaminants are exerting a negative influence in the estuary. This is one of the significant gaps mentioned in the second sentence of this paragraph. The document makes a good point in stating that the development and appropriate application of assays to the San Francisco Estuary are essential items for future research.

pg.200-204. The document describes a worst-case scenario for dredged material disposal, in which 25% of the deposited material is retained in the water column. Using this worst case scenario the document then compares the resultant suspended-solids load with bioassay results. The general conclusion is that there is no potential for impact described by the bioassays. However, the document questions the potential long-term impact on behavior and more sensitive life-stages of organisms. These are valid points that may be difficult to assess experimentally, but, again, the bioassays used are those required by US EPA regulations.

pg.206. 2nd and 3rd paragraph. The document addresses the unsubstantiated claims that dredged material has destroyed fisheries habitats, by increased

siltation. The document does this by pointing out how unlikely this is considering the energy regime in central San Francisco Bay, and using several studies to corroborate the lack of degradation.

pg.204-207. This part of the document deals with the effects of sediment burial on benthic organisms at or near the disposal site. It concludes that some, but not all, organisms can avoid burial by burrowing upward. This section ignores the fact that the disposal area and the area nearby have been determined as suitable as a disposal site. The dump site should have been selected in such a way as to minimize adverse impacts, but cannot be expected to remain as it was prior to its use as a dump site. It is concluded that the benthic community could be expected to re-establish itself rather quickly after the cessation of dumping. It is noteworthy that the Alcatraz Island Dump site has been in use since before the turn of the century and it has only been recently that concern was expressed over any unacceptable adverse impacts which may be occurring outside the site.

pg.251 3rd paragraph. This section allows that the precise relationship between laboratory tests using contaminated sediment and the effects resulting from the disposal of the sediment will probably never be determined. The document states that laboratory studies could provide useful information particularly for testing "worst case" scenarios, and calls for a more objective method by which results of sediment testing could be evaluated. This seems to be the *status quo*. The document goes on to call for studies to investigate causal mechanisms of toxic responses. This last, although needed, and scientifically interesting, may not be within the purview of the regulatory community.

pg.252-253. SEC.4 *The Bioavailability...* This section calls for the implimentation of biomonitoring stations using the california mussel (*Mytilis californianus*). The mussel watch program has shown many flaws with this type of monitoring program, but some specific flaws apply to this type of biomonitoring around dredged material disposal sites. During dumping these mussels can be expected to "clam-up" when exposed to high suspended solids loads, thus avoiding the contaminants associated with the dredged material if any exist. Also, the mussels will monitor not only dredged material, but any other contaminants in the water column or food-chain. The establishment of a monitoring program will not answer the questions posed by this document, but will certainly cost a great deal.

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CEWES-ES-R

CEWES-HE-S (1110-2-1403b) 23 October 1989

MEMORANDUM FOR CEWES-ES-R (Dr. Thomas D. Wright)

SUBJECT: Review of Aquatic Habitat Institute Status and Trends Report, pp 106-133 and 249-253

1. Review of the subject report was conducted by Larry Hauck, CEWES-HE-S, on 20 October 1989. The following comments are provided:

a. Page 107, 1st paragraph, 2nd complete sentence. This sentence is confusing to the reader and could be reworded to be more understandable.

b. Page 107, 1st full paragraph, last sentence. It is indeed true that sediment models have not been verified in the San Francisco Estuary at the time of this report; however, hydrodynamic models have been verified and successfully applied to the Estuary. Statement could be modified from "...although numerical models..." to "...although numerical <u>sediment</u> models...".

c. Page 108, 2nd paragraph. It is the 19-year mean tide.

d. Page 114, 3rd full paragraph. The ranges presented depended upon the specific characteristics of various dredged material sources investigated, not on strength of current. As mentioned, all simulations were conducted with the identical ebb current condition.

e. Page 118, 1st full paragraph, last sentence. Gravitational circulation may actually be enhanced by high river discharge.

f. <u>Difference of opinion</u>. Page 129, 1st paragraph. Many factors influence time-averaged transport of suspended sediments, and net water movement is only one of them. Unlike dissolved substances in which net water movement does greatly influence time-averaged transport, the complexities of sediment transport make such an assumption conjecture, given the present level of information available on San Francisco Bay. In fact, in some estuarine systems, net water movement seems to have relatively little to do with time-averaged transport, and such factors as tidal pumping dominate (see, for example Dyer, K. R. 1987. "Fine Sediment Transport in Estuaries," <u>Proceedings, Symposium on Physical Processes in Estuaries,</u> The Netherlands, 1986).

Larry Hauck

LARRY HAUCK
Estuarine Simulation Branch

CEWES-ES-R (70-1r) 6 Nov 89

MEMORANDUM FOR RECORD

Subject: Review of Aquatic Habitat Institute (AHI) Report Entitled "Second Draft, Dredging and Waterway Status and Trends Report", 12 Sep 89.

GENERAL COMMENTS

1. I have reviewed pages 20-28, 208-229, and 249-253 of subject report. I think that the authors have attempted to do a sincere and conscientious job insofar as evaluating the potential environmental effects of dredged material disposal in San Francisco Bay. However, the report contains several severe problem areas. The first of these concerns the unfamiliarity of the authors with applicable regulations and regulatory procedures. This is not surprising, as they are neither regulators nor part of the regulated community although they may be very proficient in the pursuit of science. It is very clear that they do not understand that regulatory scientists and engineers bear a burden that their academic or research counterparts do not and of which they are probably unaware. That is, the regulator must follow procedures, interpret data, and make recommendations for action based on existing regulations. In the case of Federal projects there is no latitude to expend public funds for things which would be "nice to know" but which would play little or no role in decision-making. Similarly, for permits, the same criteria, standards, procedures, etc as for Federal projects are required of applicants...no more, and no less.

2. The authors are also not entirely familiar with the roles of the various regulatory agencies under the provisions of the Clean Water Act and the Ocean Dumping Act with regard to assessing the ecological acceptability of dredged material for aquatic disposal. In both instances, the USEPA has issued regulations (40 CFR Part 230 for the former and 40 CFR Parts 220-229 for the latter) that are followed by, as appropriate, both the CE and the USEPA in the evaluation of dredged material proposed for aquatic disposal. These regulations set the procedures, criteria, standards, etc and have been augmented by implementation manuals which provide guidance within the USEPA regulations. Under the Clean Water Act permits are issued by the CE under the authority of 404(b)(1) and are contingent upon water quality certification by the state(s) under 401. Under the authority of 404(c) the USEPA may block the issuance of a permit by the CE (or a state 404 program, but that is not applicable in this case as CA does not have a 404 program). Thus, the CE and the state are the regulatory authorities under the Clean Water Act in that the former issues a permit and the latter certifies water quality compliance, without which (unless waived), a permit may not be issued. The CE does not issue itself a permit for Federal projects but each project must undergo the same evaluation as a permit and must have water quality certification from the state (unless waived).

3. In the case of the Ocean Dumping Act the CE is responsible for the issuance of permits for the disposal of dredged material in ocean waters and follows the requirements set forth in USEPA regulations. The USEPA acts in a

review capacity to determine if the proposed dumping complies with the USEPA criteria and may either concur or non-concur with issuance. In the event of non-concurrence no dredged material permit shall be issued unless a waiver is requested and granted. As under the Clean Water Act, the CE does not issue itself a permit for Federal projects but subjects them to the same testing procedures and criteria as those for permit applicants.

4. It is important that the authors recognize that regulatory programs are not and cannot be research programs. This is not to say that information developed within the course of normal regulatory action cannot be utilized for research purposes and, in fact, it frequently is. Tests employed within a regulatory program must be technically and legally defensible and sufficiently developed that they yield consistent results which can be consistently interpreted at the decision-making level. Further, they must also be within the context of applicable regulations. Where the regulations detail specific procedures such procedures must be followed unless there are compelling reasons for deviation. Procedures and/or tests which are in a research and development mode and those which do not comply with those specified in the regulations are not acceptable in a regulatory program. The issue of consistency and compatibility of Federal/applicant evaluatory requirements is addressed in Regulatory Guidance Letter 87-8 and 33 CFR, Parts 335-338. The latter also addresses the problem of testing/evaluatory procedures which may be of questionable validity or utility in the decision-making process.

5. The report contains numerous personal communications from individuals in USEPA Regions IX and X. Rather than contributing useful information, these personal communications are largely complaints regarding various procedures and data interpretation and presumably represent the position of USEPA. It should be noted that the majority of these complaints concern regulatory requirements by USEPA or which were jointly developed by USEPA and the CE. This report would not seem to be the proper forum for such complaints. Rather, they should work within their own agency to bring about changes in the regulations which govern CE activities.

6. Some of the references the authors cite have, at the request of the San Francisco District, received detailed technical review by the Waterways Experiment Station. A specific example is Segar, 1988. Further, the Waterways Experiment Station also reviewed Gunther, A.J., J.A. Davis, and D.J.H. Phillips. 1987. An Assessment of the Loading of Toxic Contaminants to the San Francisco Bay-Delta. Technical Report, Aquatic Habitat Institute, Richmond, CA. That report would seem to be highly relevant to this report but is not cited in the references. The technical review comments on these reports and other documents are available from the San Francisco District. An additional document which should be included in the report is, Segar, D.A. 1989. An Assessment of Certain Aspects of the Environmental Impacts of Dredged Material Dumping in San Francisco Bay. Tiburon Center for Environmental Studies, San Francisco State University, Tiburon, CA. Detailed technical review of that report is in progress and should be available in the near future. An overview and review of pages 12-18 and Appendix 1 have been provided to the San Francisco District.

SPECIFIC COMMENTS

page 20, last paragraph: These laws were not enacted to prevent adverse

environmental impacts but, rather, intend to prevent unacceptable adverse impacts. There are few actions which can be shown to have no adverse impacts; it is a societal decision as to whether or not to accept such impacts. In the case of dredged material disposal there will almost always be adverse physical impacts such as the burial of organisms at the disposal site and dredging itself will destroy organisms. In evaluating the overall acceptability of a particular action the regulatory agency must take into account many factors which, of course, include environmental considerations.

page 21, line 1: Under section 404 of the Clean Water Act the CE issues permits for the discharge of dredged material into "waters of the U.S ", not all of which are "inland". The second paragraph on this page referencing "coastal waters and the open ocean", taken in concert with the above reference to "inland waters", implies that 404 does not include marine disposal, which is not correct. A figure such as Figure 1 in OTA O-334 would be of use in clarifying this. Note also that there is overlap in the jurisdiction of the Clean Water Act and the Ocean Dumping Act. Although the latter (Sec. 106(d)) preempts the former the CE does, as a matter of comity, seek state 401 certification in such cases (see 33 CFR 336.2(c).

page 24, lines 10-12: Although the states, under 401 authority, may require whatever chemical or biological tests they consider necessary, the CE will evaluate such requirements under the provisions of 33 CFR 337.2 to determine if they comply with the requirements of the Federal standard and, should they not, take appropriate action.

page 211, lines 21-23: The comparison of the dredged material with material at the disposal site has nothing to do with the Federal standard as found in 33 CFR, Parts 335-338. It is a requirement of USEPA regulations at 40 CFR 230 and must be followed by the CE until such time as USEPA revises the regulations to specify some other procedure.

page 213, last two lines and first four lines on page 214: As per USEPA regulations at 40 CFR 230 statistically significant mortalities in water column bioassays must be interpreted with consideration of mixing to evaluate potential water quality impacts. Likewise, the procedures used in the calculation of dilution in the mixing zone are specified by USEPA regulations (see 40 CFR 230.64 for the Clean Water Act and 40 CFR 227.27 and 227.29 for the Ocean Dumping Act). As noted in the previous comment, the CE is legally required to follow the procedures specified by the USEPA regulations until the regulations are revised to specify some other procedure.

page 214, lines 17-21: The CE does not "favor" acute toxicity bioassays; such bioassays (as opposed to sublethal or chronic) are required by USEPA regulations at 40 CFR 230. The evaluation of bioaccumulation potential is considered to be a form of sublethal response and has been in routine use for many years. At the present time there are no other procedures other than those specified in USEPA regulations that are suitable for regulatory use although both the USEPA and the CE are conducting research to develop tests which do not have mortality as an end point. When such tests become available it is anticipated that they will be incorporated into the appropriate USEPA regulations.

page 214, line 31: As noted in the previous comment, work is underway to

develop sublethal tests. It is of interest that of all of the techniques evaluated during the Field Verification Program only three were found to be useful and one of these, bioaccumulation potential, was an existing procedure in widespread use.

page 215, lines 6-8: This statement is not correct. First, under the Ocean Dumping Act, acute toxicity in solid phase bioassays must be statistically significant and at least 10 percent greater in the dredged material than in the reference. Control mortality must not exceed 10 percent for the tests to be considered valid. If mortality is statistically significant and is 10 percent greater than the reference, this is not a "fail"; it merely indicates that, as is stated, a real probability exists for potentially undesirable effects. Whether or not those effects are unacceptable is a subjective evaluation.

page 215, second full paragraph: The Federal standard has nothing to do with the interpretation of test results other than as it reiterates that the CE must follow all applicable rules and regulations in the evaluation of dredged material proposed for aquatic disposal. This entire paragraph does not address controversial aspects of the Federal standard. Rather, it addresses various aspects of USEPA regulations relative to the Clean Water Act and the Ocean Dumping Act. The critics appear to be criticizing the regulations of their own agency.

page 216, third paragraph: It should be made clear that the CE does not require the larval bivalve test for Federal projects nor for the issuance of 404(b)(1) permits. This is solely a state requirement for 401 water quality certification. There is also confusion between the discussion in the preceeding paragraph regarding the various tiers and those presented in Fig. 40 on page 217 as both the text and the figure indicate that the CE requires the larval bivalve test, which it does not. The larval bivalve test, if used at all, is used in Tier 3 to address water column concerns. Additionally, it should be pointed out that the requirements for the testing of sediments do not require formalization in the publication of a public notice as they are already formalized by publication as USEPA regulations.

page 222, lines 5-7: Special studies are not needed to evaluate trace contaminants. These are evaluated through the use of water column and benthic acute toxicity tests and/or bioaccumulation potential tests. See 40 CFR 227.6).

page 222, second paragraph: This paragraph is gibberish. It seems to imply that the physical effects of sediment deposition upon a disposal site are not considered, but somehow should be. As noted above, there will undoubtedly be such effects; they should be taken into account during the process of selecting or designating a disposal site. The process is very comparable to that of selecting a site for a sanitary landfill...whatever was there before the landfill will not be there during operation and may or may not be there after the operation. Disposal sites should be chosen with this in mind. In other words, you cannot have a disposal site without some degree of disruption and sites should, obviously, be those where it is acceptable for such disruption to occur. The last sentence of the paragraph is totally incomprehensible. Was something omitted?

page 222, last paragraph: As with the preceeding paragraph, this paragraph

makes little sense. The authors jump back and forth between the Clean Water Act and the Ocean Dumping Act; their misunderstanding of USEPA regulatory requirements of the two Acts is painfully evident. First, it is stated that the interpretation of acute toxicity tests under the Ocean Dumping Act is "firmer than that offered by the USCOE for the disposal of dredged material to inland waters under section 404 of the Clean Water Act". This is totally irrelevant with regard to dredged material disposal in San Francisco Estuary, which is what the title of their report purports to address although they somehow seem to frequently digress and confuse the USEPA regulatory requirements of the two Acts. In actuality, a better term than "firmer" would be "less flexible". There are major differences between the Ocean Dumping Act and the Clean Water Act and the regulations promulgated by the USEPA recognize these differences, as they must, because their regulations must be consistent with the Acts. Inconsistencies between the Acts can only be remedied by Congressional amendment of the Acts and, in fact, if the Congress were to make the Acts identical, USEPA could presumably revise its regulations such that all dredged material disposal would be governed by a single uniform regulation and the differences between the Clean Water Act and the Ocean Dumping Act would vanish. Perhaps the authors should consider incorporating such a recommendation, if they feel it advisable, into this report. As previously stated (see especially the comment for page 215, lines 6-8), the discussion here regarding statistical significance, controls, and mixing (particularly for the solid phase acute toxicity tests and the evaluation of bioaccumulation potential) is not correct.

page 223, line 11: I do not understand what is meant by "difficulties in the detection of contaminants in the early rounds of elutriate analyses". If it is implied that laboratory procedures or detection limits were a problem, that is not correct. It is correct that contaminants were rarely detected with the USEPA required procedures. This has generally been the case on a national basis and is interpreted to mean that contaminants are not released and, hence, are not biologically available. The real reason that attention was shifted from the water column to the benthic environment was the conclusion that ecological effects from contaminants in the water column was not of great concern. This is in accordance with 40 CFR 230.60(b).

page 228, last line: These are not controversial aspects of the Federal standard; they are within USEPA regulatory requirements and represent the state-of-the art.

page 229, lines 10-11: From a philosophical and ecological point of view there would appear to be no technical justification for differences in the evaluatory approach of dredged material under the Clean Water Act and the Ocean Dumping Act. However, there are significant legal differences in the two Acts and in the regulations that implement them. Until the Acts are amended and the regulations revised regulatory agencies must conform to the procedures set forth in the regulations as regulations carry the force of law. As noted in a previous comment, the authors might prepare model legislation to eliminate these differences and work through their elected representatives to bring about change. As matters stand much of the report consists of "cursing the darkness rather than striking a light".

page 229, lines 18-20: There is provision in the regulations for the field measurement of contaminants and this approach has been employed in a number

of instances. However, several significant difficulties need to be pointed out. First, it is often impossible to collect sufficient biomass of a given species because benthic organisms are not uniformly distributed. Second, the physical effects of repeated disposal either prevents recolonization or leads to the establishment of a community of very small organisms (so-called pioneer species) which are unsuitable for bioaccumulation studies. Even where field efforts have been sucessful there is always doubt as to whether the organisms bioaccumulated contaminants from dredged material rather than other known and unknown sources. Caged animals have also been used but this is expensive because of deployment and retrieval and, again, knowing the source of the contaminants. Because of these difficulties laboratory studies have been much more widely used in the regulatory program so that the confounding effects of various contaminant sources and other uncontrolled variables do not cloud interpretation. As a point of interest, both Federal and state agencies routinely monitor contaminants in edible species. I am not aware of any closures which have been linked to dredging or to dredged material disposal.

Dredged material is not inherently contaminated. This material comes from somewhere outside of the navigation channel and is transported through the aquatic system to the channel. It may be contaminated at its origin or may become so during transport. No matter where, organisms are exposed to the material thoroughout the total transport phase as well as the sources of the contaminants. This exposure and the transport phenomena overwhelm disposal and one must intuitively conclude that if bioaccumulation or toxicity would occur at any time all of the organisms would have died or become contaminated without any disposal activities. Where disposal is in an estuary, the dredged material is often not appreciably different than most of the material in the estuary as a whole. The regulations take this into account in that assessments of toxicity and bioaccumulation potential are evaluated in comparison to a reference, i.e., the disposal site or disposal site environs.

page 251, lines 28-34: The suggestion that criteria be developed is really not needed. USEPA has developed criteria and published them as regulations. In some instances there is latitude to modify them to meet regional or local concerns but such modification may require that a regional or local agency meet any additional costs. As an extreme example a state has the authority to prohibit any dredged material disposal in state waters. If the material were found to be suitable for open-water disposal under Federal criteria the state would be required to bear those costs above open-water disposal costs or Federal dredging would not occur. Considering the alleged controversy over the adequacy or appropriatness of existing criteria and guidelines any significant changes which would be legally and technically defensible seem remote. It is worth noting that both the state and USEPA would appear to have ample authority under 401 and 404(c), respectively, to control disposal under the Clean Water Act and USEPA has "veto" authority under the Ocean Dumping Act. The extant use of these authorities should be discussed..

page 252, 3.: Modeling to determine transport back into navigation channels is a worthwhile endeavor in that it may reduce re-dredging of the same material with attendant cost-savings. Tracer studies to determine if dredged material disposal creates "hot-spots" is doomed to failure. First, because the dredged material is evaluated in terms of a reference within the system, it should behave as does the rest of the material being transported about

the system and thus be indistinguishable. Second, if there were "hot-spots" currently in existence it seems that someone would have found them. Finally, although I am not familiar with the use of bacteriophages as tracers it would seem that if they are present in the dredged material they would be equally present throughout the estuary and hence of limited value as tracers. If these bacteriophages are to be introduced into the system there might well be significant local opposition to their introduction.

page 253, line 4: It is not clear how the proposed "mussel watch" would relate to dredged material disposal. The mussels integrate all of the contaminants whether from dredged material or elsewhere. NOAA has been conducting such studies for a number of years and their conclusions relative to contaminants and effects on organisms (NOAA Technical Memorandum NOS OMA 44, Nov 88, page 14) are as follows:

"More important than the distribution of contamination itself is the distribution and spatial scale of locations within which marine organisms are responding to contamination. There are no reliable criteria with which to extrapolate levels of sediment contamination to the presence of biologicl effects and we cannot claim, a priori, that the areas found to be highly contaminated are necessarily places where biota have been affected."

Biomonitoring with mussels was used during the Field Verification Program and uptake of contaminants was noted immediately post-disposal and following disturbance of the dredged material mound by a hurricane. However, the uptake was minimal and of short duration despite the fact that highly contaminated sediments were disposed. That uptake would occur was predicted by bioaccumulation studies in the laboratory prior to disposal.

page 253, 6.: Water column tests are already in existence and have been widely used with larval stages of commercially and recreationally important species. Simulation of actual field conditions is essentially impossible because the discharge is an instantaneous event following which the concentration of suspended particulates and any dissolved contaminants become dispersed/settled or diluted. This is controlled by a number of physical processes, such as currents, nature of material, etc, and although it can be modeled each disposal will be somewhat different. The laboratory procedures are a worst-case approach whereby there is no dilution or dispersal following the introduction of the organisms, thus exposing the organisms to concentration/time relationships which would occur only for seconds to minutes in the field. Results are evaluated with consideration of the mixing which does occur in the field.

SUMMARY

7. The portions of the report which I reviewed are in need of significant revision. The authors do not understand the role of regulatory agencies, the constraints under which the agencies operate, nor the applicable regulations. A good start would be for them to read the regulations. There are numerous critical opinions expressed by individuals relative to the adequacy of the regulations. It should be clearly indicated whether these criticisms are the personal opinions of the individuals or if they represent the official position of their agency. The authors seem...as is their privilege...to have concluded that dredged material disposal is having a variety of adverse effects but that the procedures used to evaluate the

potential for such effects are such that the effects are not detected or evaluated. Having, up front, concluded that something is wrong they then proceed to suggest a number of procedures, tests, etc to verify that something is indeed wrong. There is nothing wrong with such speculation and speculation is an important part of science. However, it must always be identified as such and not purported as fact.

8. The authors appear to be sincerely concerned about the health of the San Francisco Estuary but they are missing the source of the problem. The problem is not contaminated dredged material but the contaminants which contaminate dredged material from point and non-point sources. If these were to be controlled by the responsible state and Federal agencies there would be little, if any, contaminated dredged material other than that which is currently in-place. It is my understanding that the San Francisco sewage outfall has a waiver from USEPA. In other words, it does not meet discharge criteria. I am not aware of dredged material in San Francisco or anywhere else which has required such a waiver.

9. The report places major emphasis upon inconsistencies in evaluatory procedures under the Clean Water Act and the Ocean Dumping Act but the solutions proposed by the authors fail to take into account that the procedures are mandated by regulations which must conform to the Acts. I would hope that they would take a more constructive approach, such as designing amendments or proposing new legislation. In the long-term, this will be more productive than complaining about the current situation or suggesting solutions which cannot be implemented because of legal or institutional constraints.

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1833JM/P3-260
31 OCT 1989

Mr. Michael Monroe
San Francisco Bay Delta Aquatic
Habitat Institute
180 Richmond Field Station
1301 South 46th Street
Richmond, CA 94804

Dear Mr. Monroe:

This is in response to your letters dated 22 and 26 September 1989 requesting the Western Division, Naval Facilities Engineering Command to review two draft reports entitled "Status and Trends Report on Dredging and Waterway Modification in the San Francisco Estuary" dated 12 Sept 1989 and "Status and Trends Report on Wetlands and Related Habitats" dated Sept 1989.

This office has reviewed the draft reports and is submitting the enclosed comments. Enclosure (1) contains our comments on the Dredging and Waterway Modification Report while Enclosure (2) contains our comments on the Wetlands and Related Habitats Report. Overall the reports are thorough and appear to present a state-of-the-art knowledge on the issues.

If you should have any questions, the point of contact is: Commander, Western Division, Naval Facilitlies Engineering Command (Attn: Mr. John A. Montella, Code 1833JM at (415) 877-7696), San Bruno, CA 94066-0720.

LCDR LEE MICHLIN
Director, Office of Environmental
Management

Enclosures:
(1) Navy comments on "Dredging Waterway Modification Report"
(2) Navy comments on "Wetlands and Related Habitats Report"

Copy to:
Mr. Thomas Wakeman, COE-SF

COMMENTS
Dredging and Waterway Modifications

Page 6, line 10:

Regulatory actions should not be taken or made without sufficient scientific data to support such actions. Additionally, a scientific report should not overtly champion a specific regulatory position.

Page 16, line 1:

A statement should be added that discusses the probability that material other than sediment was routinely deposited at Alcatraz (i.e. construction demolition debris material, chunks of concrete, etc.) and what effect this type of non-sediment disposal may have had on the mounding problem.

Page 17, line 17:

The bio-availability of chemical contaminants was investigated by Corps of Engineers Waterways Experiment Station (WES) in 1985/86 for the U.S. Navy Homeporting Environmental Impact Statement (EIS) at Everett, Washington. Results of these investigations seem to suggest that if the chemical contaminants in the sediment are not allowed to oxidize, these contaminants remain sediment bound.

Page 27, line 23:

A statement about overfishing should be added as possibly being a contributory cause to influences on fishing success.

Page 28, line 1:

Specific names of user organizations, i.e. port authorities and Bay area commercial organizations, should be added to balance the references to environmental groups.

Page 28, line 7:

Change first sentence to read, "These organizations have often entered into litigation brought about by <u>both</u> special interest groups and direct users".

Page 35, Table 1:

Change the following quantities:

Treasure Island NS	42,000	1	457,000	1985
Hunters Point NSY	32,000	2	180,000	1983
NAS Moffett Field	19,000	1	207,000	1979

Enclosure 1

Page 133, line 7

It would be clearer if a quantity/percentage of resuspended/reworked sediment is indicated in comparison to the "New" inflow from the delta/Central Valley.

Page 135, line 2:

The COE has done disposal impact studies on direct burial effects. Include the results of these studies which have indicated the reestablishment of benthic communities.

Page 191, line 18:

Eye witness accounts by fishermen regarding aerial extent and duration of turbidity plume seem to be a less than scientifically supportable perspective.

Page 193-194, line 29:

The other possible explanations for reduced fishing success referred to should be added to the sentences.

Page 197, line 9:

The report creates the impression of having a bias against dredging, rather than presenting only scientific data.

Page 240/241, Short-Term:

Item 1.1 - The USCOE, USEPA and RWQCB (not BCDC) have informally adopted a sediment testing protocol which has been in effect for better than 5 years.

Item 1.6 - There should be a discussion in the report addressing the sources/routes of contamination into the bay.

Page 241/242, Long-Term:

Item 2.1.2 - Prioritizing dredging projects may be desirable in theory, but in reality it is very difficult to rank National Defense, vs Port Authorities, vs small marinas, on environmental, economic and social factors. How would one rank Port Authority projects, which are high on the economic scale, versus small marinas which rank higher on the social factors scale. Many conflicting tradeoffs and priorities may be involved.

Item 2.1.4 - We believe that Federal facilities should not be singled out for elimination. The elimination of Naval facilities that require dredging would have an adverse and unacceptable impact on U.S. defense capabilities.

Page 242, line 4:

Item 2.2.1 - The economic impact of this option is a critical factor. The Navy's position is that if an alternate disposal site (ocean) is designated by USEPA and COE, the Navy would look to disposal at such a site. However, the taxpayer will utimately pay the additional costs. Also the additional costs that would be incurred by the Port Authorities and small marinas would be passed onto the users of their facilities, ulimately the consumer.

Page 243/244, Section 2.5:

The tone of the document may create the perception that dredging and dredged material disposal is the cause for bay contamination, when in reality dredging results in the transporting of existing material from the dredge site to the disposal area. There should be discussion concerning the sources of contamination; the Federal/state regulatory programs/agencies; and effectiveness of actions to control and prevent these toxic materials from entering the estuarine system. The very agencies which propose to reduce/eliminate dredging are the ones responsible for controlling the input of toxic materials (USEPA, RWQCB, Cal F&G).

Page 293, References:

"IEC (1974)" and presumably, "IEC (1973)" reports are authored by IECO (International Engineering Corporation), not Interstate Electronics Corporation.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
215 Fremont Street
San Francisco, Ca. 94105

SUBJECT: REVIEW OF STR ON DREDGING
+ WATERWAY MODIFICATION

10/24/89

Hi Mike: As discussed on the phone today, enclosed please find the following:

1) Letter to Bob Spies from Rick Swartz and Ted DeWitt in response to Bob's proposed editorial on solid-phase bioassays;

2) Letter to Steve Ritchie from Bob Spies describing Bob's concerns about the use of sediment bioassay results;

3) A copy of Bob's editorial to Marine Environmental Research;

4) Highlighted "controversial" language found in the STR which describes why sediments may be toxic to benthic critters; and

5) Copies of pages where spelling and editorial mistakes were made.

I strongly recommend that Rick Swartz be contacted so he can: 1) review the Sediment Toxicity Section found on pages 164-172; and 2) respond to Bob's editorial since Bob's editorial was cited in the STR. Again, I feel that the second Draft is much improved over the first DRAFT and all participants at ANI, etc should be commended for their efforts. Regards, Brian (401) 782-6163

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region, HCB
777 Sonoma Avenue, Room 325
Santa Rosa, California 95404

October 18, 1989 F/SWR13

Mike Monroe
Technical Program Manager
San Francisco Estuary Project
Post Office Box 2050
Oakland, California 94604-2050

Dear Mr. ~~Monroe~~: Mike

We reviewed the second Draft Status and Trends Report on Dredging and Waterway Modification in the San Francisco Estuary. Based on the authors response to our concerns and criticism of the first draft, we believe the current draft represents a sound and impartial assessment of dredging and waterway modification in the San Francisco Estuary, and development of the Comprehensive Conservation Management Plan.

The DSTR raises a number of questions on the fate of contaminants in dredge material in the marine environment. The author's use of existing information adequately characterizes what is known about dredge sediment toxicity and the fate of contaminants in the marine environment. This characterization points to the fact that further research is required. Filling the data gaps listed in the DSTR would contribute significantly to the knowledge of all resource management agencies and constituent groups.

We look forward to using the final STR as the basis for initiating discussion toward resolution of issues related to dredging, dredge disposal and waterway modification in the San Francisco Estuary.

If you have questions regarding these comments, please contact me at NOAA Fisheries, 777 Sonoma Avenue, Room 325, Santa Rosa, California 95404; telephone (707) 578-7513.

Sincerely,

Patrick

LCDR Patrick J. Rutten
NOAA Fisheries

United States Department of the Interior

GEOLOGICAL SURVEY

345 Middlefield Road (MS-496)
Menlo Park, California 94025

December 4, 1989

Mr. Mike Monroe
Technical Program Manager
San Francisco Estuary Project
P. O. Box 2050
Oakland, CA 94604-2050

Dear Mike,

I have just now received the 2nd draft of the Status and Trends Report on Dredging and Water Modification. You may recall from my comment at the TAC meeting that I never received the 1st draft, so I have not offered any comments heretofore. I will try to get through this draft in the next several weeks and send any comments then. However, my initial scan through this most recent draft exposed what I consider to be a major omission: there is no discussion of the effect of channel deepening on salt water intrusion.

I assume that the saltwater intrusion issue should have been discussed in the waterway modification section, but somehow the issue has fallen through the crack. There is simply no mention of it. I think this is a critical issue in several respects as pointed out, for example, in the brief comments on this subject in the attached pages from the USF&WS Community Profile by Nichols and Pamatmat (1988). Because of the past and probable future deepenings of the Baldwin Ship Channel, for example, this is an issue that needs to be addressed here. While salt intrusion is to a large degree influenced by freshwater inflow management decisions, the influence of channel deepening is sufficiently great that the discussion of this issue should not be left solely to a future "flows" Status and Trends Report.

I apologize for not having been in a position to point out this omission earlier in the review process.

With best regards,

Fred

Frederic H. Nichols

cc: T. Wakeman and T. Mumley, SFEP TAC Co-Chairpersons

LEONARD O. LONG
1522 EAST SHORE DRIVE
ALAMEDA, CA 94501

OCTOBER 24,1989

Mike Monroe
San Francisco Estuary Project
c/o ABAG, Metro Center
101 Eighth St.
Oakland, CA 94607

Subject: DREDGING AND WATERWAYS MODIFICATION - STR REVIEW

Dear Mike

The comments in this review are mainly directed toward subjects with which I am familiar - geotechnical engineering,hydraulics, and recreational boating. There are both general and specific comments followed by gratuitous editorial comments.

1. GENERAL COMMENTS

1.1.1 Sediment Transport

There is no reference to the considerable body of data regarding tidal currents contained in the 1988 NOAA publication "Tidal Current Tables 1989 - Pacific Coast of North America and Asia". These tables contain results of many tidal current velocity measurements in the Estuary, which include many measurements of deeper current velocities as well as surface velocities. These data are based on direct measuremenmts and show that there are no deep reverse currents as the authors seem to have inferred from reports of bottom drifter studies. The data also show that changes of tidal stages occur much earlier along both the south and north shorelines than in the central part of of the channel leading from the bay, which may in part account for some of the observed paths of bottom drifters. These early tide reversals are also evident during operation of the Bay Model. I have also noted from personal experience that the currents along along the north shore of the Golden Gate channel are predominantly easterly even during ebb stages owing to back-eddies westerly of Pt.Diablo and Lime Point.

1.1.2 The report contains no doubt of the wisdom of permitting disposal at the permitted sites when the tidal currents are flooding. It seems evident that disposal during flooding currents is not efficient.

1.1.3 The Alcatraz disposal site is not nearly as dispersive as deeper waters to the west.

1.2 Recreational Boating

1.2.1 There is a comment about rcreational boating in Part I, in the first paragraph of the introduction, but there are no further references in the report. Some discussion of two aspects of recreational boating should be included in Part II:

1) The deterioration of the quality of the delta for recreation due to removal of trees and shrubbery during levee repairs
2) The erosive effects of wakes caused by boats travelling at high speeds.

1.2.2 If Management Options are appropriate in Part II, the follow[illegible] might be included:
1) Include tree and shrub planting as an integral part of levees repair
2) Remove all vegetation from the levees as a preventative measure
3) Enforce speed limits in areas sensitive to wakes.

1.3 Waterway Modification -Shoreline Erosion

Ground subsidence is not recognized in the report as a basic cause of shoreline erosion nor has it always been recognized where it is happening. The south shore of Alameda is a good example. Alameda's south shore fill area is underlain over much of its area by thick deposits of Bay Mud and the fill is a predominantly sandy soil dredged from the adjacent bay to the west. The soil engineering consultant estimated that the soft clays underlying the fill would settle as much as 5 feet over a period of time exceeding 50 years. Upon completion of the fill there was a broad beach extending above the high tide line to a relatively steep embamkment of the sandy fill between the beach and the adjoining street. The predicted settlement has been occurring, and the high tide has consequently reached the steep embankment causing it to erode and threaten stability of the street.

The beach has been replenished by a coarse, sandy soil dredged from the Alcatraz disposal site. The course soil was specified for the work because of its greater resistance to erosion than the finer soil available from the original nearby borrow sites. The need for this expensive requirement is dubious because the basic cause of the problem is subsidence, not erosion, which is a consequent problem. Subsidence will doubtless continue under the weight of the added sand, and "erosion" will again threaten the steep embankment.

2. SPECIFIC COMMENTS

2.1. p12, 1st full par. Is the 4.83 million tonnes of sediment now entering the Estuary considered to be an equilibrium value?

2.2. p30, 1st full par. Where is "Southhampton Bay"? (Southhampton Shoals?)

2.3. p109, 1st full par. The mounded shape should have little effect on behavior of disposed materials compared to behavior on level bottoms. If you plot the "mound" to equal horizontal and vertical scales it becomes evident that the "mound" has very gentle slopes.

2.4. 1st full par. The difference between surface currents and deeper currents are not sufficient to invalidate an averaging

approach to the TABS-2 model. (See previous comments regarding actual current measurements by NOAA)

2.5. p113. 2nd par. It would be expected that large clumps of cohesive material such as clamshelled Bay Mud would settle rapidly owing to the large effective radius of each clump, and that some of each clump would remain on the bottom undispersed. These clumps would not be entrained by the moderate currents at Alcatraz owing to their cohesive property.

2.6. p251, 1st full par. Add "stage of the tidal current" to the list of records of disposal activities that should be kept in the future.

2.7. p275, 1st par.,last sentence. Does not include subsidence as the underlying cause of erosion in some areas. See initial comments.

2.8. p283, (ii) Add "Have underlying causes of shoreline erosion at all locations been correctly assessed?"

3. EDITORIAL COMMENTS

3.1. p10, 1st par., 1st sentance. There is no logic in this sentence.

3.2. p29, 1st. par. Delete comma after "provided" or "()" around the paranthetical clause. Insert "both" between "sites" and "in". (or start over)

3.3. p31. First evident here, but generally applicable- The section labelling format can be confusing. For example, after IVA2A when B is encountered, it is not clear whether it is IVB or IVA2B

3.4. p35, Table 1. The "1,896,000" on the same line as "Oakland Army Base" should be on the same line as "TOTAL".

3.5. p122,2nd par.,last sentence. The reference to "surface sediments " is confusing. "upper 23 cm of the bottom sediment" would clarify it. (I first thought the reference was to the entrained sediments in the 23 cm below the water surface)

3.6. p129,4th par. and p130 It is my opinion that bottom drifter studies have been misinterpreted.(See initial comments)

3.7. p134, 1st par. There is duplication of the words "Sensitivity analyses should be undertaken". The first occurrence should be deleted?

3.8. p246, 1st full par. Is "covary" scientific jargon? "co-vary" would be more comprehensible to non-scientists.

3.9. p248. (iii) Add "Would disposal only during ebbing currents improve sediment removal from the bay?"

3.10. p251, 1st full par. Is something missing from the

opening clause? The sentence scans OK without it.

3.11. p252, 1st par. "covary"?

3.12. p253, 5. The clause starting "with an emphasis.." needs help. Add "of" after "contribution"?

3.13. p261, 1st full par., first sentence. Needs some help.

3.14. p263, 3rd par., last clause. "...Delta islands are now more than 6m(20ft)." Needs something else. Add "below some water level"?

---

end of comments

I appreciate the opportunity to submit these comments.

Leonard O. Long, Civil Engineer

Leonard O. Long

Alternate Delegate to MAC

Representing PICYA

October 23, 1989

Mr. Mike Monroe, Technical Program Manager
San Francisco Estuary Project
P.O. Box 2050
Oakland, CA 94604-2050

Dear Mike:

Here are my comments on the Dredging and Waterway Modification Status and Trends Report. They express my own concerns, not necessarily those of the League of Women Voters of the Bay Area. My chief concern is the lack of attention to the effects of dredging on the Delta.

Sincerely yours,

Arliss

Arliss L. Ungar
517 Silverado Drive
Lafayette, CA 94549

PS Since no one answers the phone at your office, I'll assume these comments are not too late for consideration. Thanks

A.U.

DREDGING

1. Although the authors are careful to use the terms "Estuary" and "Bay and Delta", except for the deep water ship channels and a few pages on levees, the estuary seems to end at Suisun Bay. Dredging in the Delta is virtually ignored.

There is no mention of maintenance dredging of small boat harbors and marinas in the Delta. While the amount of sediment to be disposed of is relatively small, it is of vital importance to those involved. Because dredging equipment must be relatively small and direct ocean disposal is infeasible, their manageament options may be different from those of large Bay dredging operations.

There is no discussion of possible adverse environmental effects of dredge disposal at Twitchell Island and Upper Jones Tract.

2. There should be discussion of possible adverse environmental effects of dredging on the area dredged.

What are the possible adverse effects of further dredging of deep water ship channels in the Delta on salt water intrusion?

What are the environmental effects of dredging by Reclamation Districts for levee maintenance and repair?

WATERWAY MODIFICATION

The statement in Appendix 4, p. A 4-5, "A significant impact of channelization on the Estuary is the effect of fresh water inflows which was specifically excluded from the scope of this report", should be prominently placed in the introduction, not just buried in the appendix.

No serious discussion of waterway modification can ignore the effects on the Delta channels and levees of transporting at least current levels of water through the Delta (even if you must exclude the effects of outflow on the fishery)

There should be mention of possible effects to the levee and channel island vegetation of waterway modification (dredging, levee setbacks) to increase channel capacity.

There should be greater discussion of the effects of vegetation on levee erosion.

There should be discussion of the environmental and economic costs of dredging for acute emergency Delta levee repair compared to routine maintenance and repair.

Part II

p. 255
You should remove the sexist language! The use of "man" or "man's" three times on the same page (especially the first page) is just not acceptable.

p. 256, (ii)
"...local flood control projects west of the Delta..." Do you mean "in the Western Delta?"

p. 267, 2nd paragraph, 2nd sentence
Change "a large number of the" to "a few key" Delta islands.

p. 269, 3rd paragraph, 1st sentence
What about increased velocity from pumping?

p. 277, 2nd sentence
"...estimated risk of inundation of less than once in twenty years" Is that really what you mean? Or do you mean that those islands are likely to flood within a twenty year period?

p.277, 2nd paragraph, 1st and 2nd sentences
Insert and agricultural methods after "changes in land use". In the next sentence delete "funding for" so it reads "Increased levee maintenance..."

p.278, last paragraph, 3rd sentence
The end of the sentence is missing.

p.279, 5th paragraph, 1st sentene
Add on the marshplain after "The effect of rising sea level..."

p. 282
Some of the management options in the Dredging section would be more suitable under Waterway Modification, and it would help to alleviate the questions and criticism as to why the Committee listed no management options.

p. 284, 1st full sentence
Do you really mean that different land uses around the Estuary should have consistent flood protection design standards (the same for agriculture as for housing developments)?

p. 284, 2nd full sentence
Why just the Bay? How about the consequences in the Delta?

p. 284, 2nd paragraph, last sentence
"There is (also) a need for a co-ordinated long term plan for the future of the Delta" is an extremely important concept(management option) that should be stressed.

230 Prince Avenue
Melbourne, FL 32901
(407) 768-1037

Mike Monroe
San Francisco Estuary Project
PO Box 2050
Oakland, CA 94604-2050

Dear Mike,

Here is your second draft of the report "Status and Trends Report on Dredging and Waterway Modification in the San Francisco Estuary." I spent 20 hours editing the report, as we discussed. Along with the report I have enclosed a separate comment sheet with suggested changes. In addition, I marked many comments, additions, changes, and deletions on the report itself.

In an attempt to conserve time (Did you realize I spent 30 hours on the first draft?) I skimmed quickly over the reviewer's comments in Appendix 4. I also did not edit the reference entries themselves since the format comments I made on the first draft will still apply.

It was satisfying to see many of the changes I suggested in the first draft incorporated in the second draft. If you will call me, I have a couple of suggestions about the incorporation of the comments I made on this draft. Thank you again for the opportunity to work with you on this project. I look forward to working together in the future.

Cordially,

Joyce

Joyce G. Nuttall

JGN:ee
Encl: Report
Comment sheet
Invoice

Comments by Joyce Nuttall on the second draft of the "Status and Trends Report on Dredging and Waterway Modification in the San Francisco Estuary."

p4 "Man" when used to refer to human should be replaced with human, anthropogenic, etc. (see also pages 13, 255, 261)

p10 "Particulates" is not a noun but rather a mis-used adjective. "Particle" is a noun. I have substituted "particulate matter" or "particulate material." Same rule applies to "organics."

p12 For instances where two or more rivers (harbors, lakes, mountains etc.) are named, the river (harbor, lake, mountain. etc.) is not capitalized. Ex: Sacramento River and San Joaquin River but Sacramento and San Joaquin rivers.

p12 I marked N-dashes and M-dashes this time. If your typeface does not have an N-dash simply leave it a hyphen (as it already is in most cases). If your typeface doesn't have an M-dash (see pg 17), substitute two hyphens, like this --.
An N-dash goes between ranges of numerals: 3-6, 4.6-5.9.

p20 A company or agency is singular, so pronouns and verbs used in context with the company or agency are singular. Ex: USCOE...its, USEPA...is

p21 Spell out the name of a country, state, etc. when it is used as a noun; use the abbreviation when it is used as an adjective. Ex: The United States is..., Profits of U.S. companies...

p27 One of the most common sentence errors in this report is subject-verb agreement. The two sentences at the bottom of this page are good examples of the common error of mistaken subject. "As an example...., the effects ... have recently been..." "Effects" is the subject. "Their concern...has had..." Concern is the verb. This problem most frequently occurs when lots of phrases intervene between the subject and verb.

p31 The other common error is splitting a compound verb with unnecessary punctuation. In this report the error looks like Subject verb, and verb. "Such estimates are only made...and tend..." The subject is "estimates" and the compound verb is "are made and tend." It is incorrect to put a comma between the verbs. An exception to this rule would be when the comma was there for a valid reason (e.g., between coordinate adjectives, setting off a non-restrictive modifier).

A comma is placed before "and" (or another coordinating conjunction such as "but" and "or") when it connects two independent clauses.

p31 Although "Congressionally-authorized" and "Federally-funded" look like compound adjectives, they are not; generally, no hyphen is used after a word ending in ly.

p35 The tables in this report do not adhere to a common format. Set up in a consistent style, use either numerals or letters for footnotes, etc.

p36 "...from 1980-1985" is incorrect. Whenever "from x to x" is written, the "to" must be written out, and a hyphen cannot be used.

p58 Once an acronym (or initialism) is defined, the acronym really should be used consistently afterward. If the word will always be spelled out, then there is really no reason for defining its acronym (unless it is more commonly known by that acronym, like BART). I have marked in the margin when an acronym is used without being defined and have removed duplicate definitions.

p61 "20,000 tons (18,000 tonnes)" while on page 62, "463 tonnes (509 tons)." Should be consistent. A similar problem with the consistency of adding the amount in SSI units is found in the area of page 45.

p76 Spell out abbreviations at the beginning of a sentence. Ex: "Figure...."

p87 It doesn't matter which date format is chosen as long as it is used consistently. The government form (day month year) was used most often, so I changed the other dates to that format.

p89 Footnotes are placed in order of appearance in the table.

p101 References cited in the text should be in chronological order. Within a year the order is alphabetical.

p107 Does the personal pronoun "our" refer to the authors or the scientific community? Clarify. Same problem pg 119.

p118 Spell out milligrams per liter when used in the text as it is. Use the abbreviation when it follows a numeral. Liter was spelled out in the first half of the report and abbreviated L in the second half. I suggest you go with L and change the first half.

p118 The sentence fragment can be changed as follows: "In addition to the seasonal trend of sediment deposition caused by wind and sedimentation, erosion also occurs in response to the tidal cycle. As slack water..." Does this reflect the author's meaning?

p122 Names of chemical elements are spelled out and abbreviated inconsistently. You could either spell out all the time, spell out the first time and abbreviate afterward, or spell out the first time and give the abbreviation in parentheses then abbreviate afterward.

p139 Greater than and less than has been spelled out in most of the report. In this section, the symbol has been used. I suggest you spell out throughout since it would involve fewer changes. (You can use the symbol in figures and tables without being inconsistent.)

p143 See fragment at the top of the page.

p163 Insert genus species for striped bass for consistency.

p88 If you intend to include the affiliation for the personal communications cited, you should do so for all. Right now affiliations are included only in a few sections.

p171 Units should be consistent on figures and tables (use negative index).

p175 Does "...where they are bound to metallothioneins and accumulate to high concentrations and may then be accumulated by a predator." Retain the original meaning in a somewhat clearer fashion?

p178 What is a "...lower chlorinated PCB"? Can you reword?

p201 Mortality really does not seem correct in this sentence.

p203 A word is missing in the sentence "The shrimp <u>Crangon nigricauda</u> (from Bodega Bay)..."

p213 First sentence of 2nd full para: meaning is not clear. "...are interpreted with consideration of mixing."?

p235 A column is missing or the table title is incorrect.

p261 A word is missing "...and is protected against by the Sacramento..." Flooding?

p263 A word is missing last sentence of 3rd para.

p278 Words are missing second to last sentence.

p281 A word is missing 3rd to last sentence.

pA4-2 See comment 2 page range.

Reference: I marked the references cited in the text but not listed in the reference section in the margin of the text. I have also listed them at the end of the reference section. They need to be added.

Reference entries in the reference section without a red check are those I couldn't find cited in the text. They need to be cited in the text or removed.

p299 O'Connor is a good example, but this applies for all references: First list the single-author ms in chronological order; then list the two-author ms in alpha order and then chronological order; then list the et al.'s in chronological order. but, of course, with all the authors names spelled out

Where a reference is listed by acronym, if it is listed in the reference section only once, spell it out. If it is listed more than one time, spell it out the first time with the acronym in parentheses and use the acronym for the other listings.

I remember seeing REMOTS without a registered trademark symbol in one section while later it did have a trademark symbol. It should be consistent throughout. For trademark products, the manufacturer, city, state, and country of manufacture should appear in parentheses after the product's first mention.

APPENDIX 4

GOALS, MANAGEMENT ACTIONS AND MANAGEMENT OPTIONS FOR DREDGING AND DREDGED MATERIAL DISPOSAL

After reviewing the first draft of this report, the San Francisco Estuary Project's Dredging and Waterway Modification Subcommittee developed lists of short- and long-term management options for dredging. Those options identified tasks that might be undertaken to improve the management of dredging activities in the Estuary. They were presented in the second draft. Arrayed in no particular order, nor assessed in any great detail, they represented the Subcommittee's first attempt at identifying tasks that might be undertaken to solve the most important dredging problems.

After reviewing the second draft, the Subcommittee developed a set of goals for dredging. It also revised the lists of management options, replacing the list of short-term options with a more focussed list of short-term management actions, displayed below. In this context "short-term" refers to actions that should be implemented immediately, rather than waiting until the Project's Comprehensive Conservation and Management Plan is completed in November, 1992.

The Subcommittee also revised the list of long-term management options. Unlike the short-term management actions, the long-term options represent an array of potential tasks that the Estuary Project should evaluate as it develops the Comprehensive Conservation and Management Plan. The list has been described by Subcommittee members as a "blue-sky list," a "brainstorming list," a "wish list." Subcommittee members recognize that many of the options are contradictory, perhaps unrealistic, and perhaps impractical to implement. Thus, readers should view the list of long-term management options as a starting point for discussion on the kinds of actions that should be included in the Comprehensive Conservation and Management Plan.

The Subcommittee has not yet developed goals, actions or options for Waterway Modification. Those documents will be completed before the public workshops.

RESOLUTION
SAN FRANCISCO ESTUARY PROJECT
GOALS FOR DREDGING AND WATERWAY MODIFICATION

WHEREAS:

The goals of the San Francisco Estuary Project are to:

1. Develop a comprehensive understanding of environmental and public health values attributable to the Bay and Delta and how these values interact with social and economic factors; and,

2. Achieve effective, united, and ongoing management of the Bay and Delta; and,

3. Develop a Comprehensive Conservation and Management Plan to restore and maintain the chemical, physical and biological integrity of the Bay and Delta, including restoration and maintenance of water quality, balanced indigenous populations of shellfish, fish and wildlife, and recreation activities in the Bay and Delta, and assure that the beneficial uses of the Bay and Delta are protected; and,

4. Recommend priority corrective actions and compliance schedules addressing point and non-point sources of pollution. These recommendations will include short and long-term components based on the best scientific information available.

AND WHEREAS:

5. The San Francisco Estuary is a significant national resource; and

6. Navigation is an important beneficial use of the Estuary; and

7. Dredging activities -- which include dredging, transport, and disposal -- are necessary to maintain navigation in the Estuary, and

8. Dredging activities have adverse and beneficial impacts on other uses of the Estuary.

THEREFORE, BE IT RESOLVED THAT IT IS THE GOAL OF THE SAN FRANCISCO ESTUARY PROJECT MANAGEMENT CONFERENCE TO:

1. Eliminate unnecessary dredging activities in the Estuary.

2. Maximize the use of dredged material as a resource.

3. Conduct dredging activities in the most environmentally sound fashion.

This resolution was adopted by the Dredging and Waterway Modification Subcommittee, and approved by the Management Committee on March 16, 1990.

Harry Seraydarian

Harry Seraydarian

Chair, Management Committee

SAN FRANCISCO ESTUARY PROJECT
DREDGING AND WATERWAY MODIFICATION SUBCOMMITTEE
SHORT-TERM MANAGEMENT ACTIONS FOR DREDGING

The agencies responsible for the management of dredging activities in the Estuary should immediately begin to implement the actions described below. Responsible agencies include:

BCDC	-	Bay Conservation and Development Commission
SWRCB	-	State Water Resources Control Board
CVRWQCB	-	Central Valley Regional Water Quality Control Board
SFBRWQCB	-	San Francisco Bay Re Water Quality Control Board
COE	-	U. S. Army Corps of Engineers
EPA	-	U.S. Environmental Protection Agency
USCG	-	U.S. Coast Guard

Actions to be implemented:

1. All agencies responsible for managing dredging activities in the Estuary should improve coordination to achieve more efficient and effective management.

2. The agencies responsible for managing dredging activities in the Estuary (BCDC, SWRCB, CVRWQCB, SFBRWQCB, COE, EPA, and USCG), with ample public input, should develop and implement an appropriate long-term, Estuary-wide management plan for dredging activities consistent with the Comprehensive, Conservation and Management Plan.

3. Until a long-term management plan for dredging activities is implemented, all agencies responsible for management dredging in the Estuary (BCDC, SWRCB, CVRWQCB, SFBRWQCB, COE, EPA, and USCG) should:

   A. Ensure compliance with dredging permits by developing monitoring and surveillance programs and allocating adequate resources to ensure their implementation.

   B. Keep accurate records of the exact locations of dredging activities and the amounts of material dredged and disposed.

   C. Adopt or endorse, as appropriate, standard procedures for testing sediment chemistry and toxicity of proposed dredged material.

   D. Compare sediments of proposed dredging projects to reference sites rather than to propose disposal sites, in order to assess potential impacts of disposal.

   E. Adopt, as policy, actions to protect beneficial uses of the estuary. These actions should encourage, in decreasing order of preference, such activities as: 1) the re-use of dredged material; 2) disposal of dredged material at upland sites; and 3) disposal of dredged material off the

continental shelf. Actions also should encourage adjusting seasonal, tidal cycle, and volume restrictions on in-Bay disposal.

4. The BCDC, SWRCB, CVRWQCB, SFBRWQCB, COE, and EPA should expedite the development of sediment quality criteria that can be used to judge the ecological significance of dredging activities.

5. The SWRCB, CVRWQCB, and SFBRWQCB should implement, through NPDES permits and Waste Discharge Requirements, aggressive source control measures to reduce the inflow of pollutants into the Estuary and the subsequent contamination of sediments.

6. All agencies and interested parties should secure adequate funding to conduct the research and monitoring necessary to address the priority gaps in our knowledge as identified in Section VI.D. of this report.

7. As participants of the San Francisco Estuary Project, all agencies responsible for managing dredging activities in the Estuary should report quarterly to the Management Conference on the progress of the above actions.

SAN FRANCISCO ESTUARY PROJECT
DREDGING AND WATERWAY MODIFICATION SUBCOMMITTEE
LONG-TERM MANAGEMENT OPTIONS FOR DREDGING

The following options, as well as all new options developed during the public workshops, will be evaluated for potential inclusion in the Comprehensive Conservation and Management Plan:

2.1 DREDGING

2.1.1 Reduce the need for dredging through appropriate siting and design of new projects and modifications of existing projects. These projects include the construction of breakwaters and the modification of channels. Additional ways to reduce dredging demand include:

> Eliminating some federal facilities that require dredging;
>
> Consolidating port activities to more efficiently use dredged channels
>
> Avoiding unjustified dredging projects.

2.1.2 Prioritize dredging projects according to their need, costs, and benefits. This analysis must consider environmental, economic, and social factors. A decision-making framework should be established to allocate dredging resources based on this prioritization, giving highest priority to the most needed projects.

2.1.3 Establish a program to coordinate small dredging projects in order to make ocean or upland disposal more economically feasible.

2.2 IN-BAY DISPOSAL

2.2.1 Institute a ban on all in-Bay disposal.

2.2.2 Allow in-Bay disposal of maintenance material only.

2.2.3 Allow in-Bay disposal of maintenance material from small projects only.

2.2.4 Allow disposal only at fully dispersive sites, where dredged material will not accumulate.

2.2.5 Establish new in-Bay sites (including non-dispersive sites) to distribute disposal impacts across a larger area and reduce volumes disposed at each site.

2.2.6 Institute alternative dredging techniques, such as thin-layer disposal, side-casting disposal, and agitation dredging, to minimize potential impacts.

2.2.7 Adopt seasonal tidal cycle, or volume restrictions on disposal activities to minimize potential impacts on biological resources and their uses.

2.3 OCEAN DISPOSAL

2.3.1 Designate an ocean disposal site(s) in an area that minimizes impacts on marine resources.

2.3.2 Designate several ocean sites, the deeper water site for larger new projects and the shallower sites for smaller maintenance projects. Establish some shallow water sites that can be used for beach nourishment.

2.3.3 Develop a pipeline to transfer dredged material to deep ocean waters.

2.4 ALTERNATIVE DISPOSAL OPTIONS

2.4.1 Establish additional disposal sites on land around the Estuary.

2.4.2 Use dredged material to increase the elevation of some diked historic baylands so that these baylands, when restored to tidal action, will support wetlands.

2.4.3 Use dredged material in the Delta to raise the elevation of one or more islands to prevent further subsidence and levee failure, and to establish wetlands.

2.4.4 Establish effective collection and transfer techniques to allow for the subsequent rehandling and consolidation of dredged material.

2.4.5 Pump, rail, or truck dredged material to land fill sites for use as daily or permanent cover.

2.4.6 Use dredged material with or without treatment for levee maintenance or other constructive uses.

2.4.7 Use dredged material to reduce shoreline erosion.

2.4.8 Use dredged material to create wetlands.

2.4.9 Use dredged material to construct islands for wildlife.

2.5 MANAGEMENT OF TOXIC POLLUTANTS

2.5.1 Establish and expand programs to identify and control all sources of sediment contamination. These may include wet-weather overflows from point-source wastewater dischargers, nonpoint sources such as runoff from urban and agricultural lands, and discharges from port practices.

2.5.2 Apply the pollutant testing protocols used in assessing ocean disposal of dredged material for projects using in-Bay disposal sites.

2.5.3 Establish numerical limits for pollutant levels in material proposed for dredging.

2.5.4 Reduce or eliminate pollutant testing for future maintenance dredging at any site that has already passed existing pollutant screening.

2.5.5 Establish aquatic sites where contaminated sediment can be deposited and then "capped" with uncontaminated sediment to reduce potential toxic impacts.

2.5.6 Establish sites on land for the disposal of contaminated sediments where containment or treatment is used to reduce toxic impacts.

INDEX[1]

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[1] Page notations in bold type refer to pages where a given subject is discussed in detail.